HEALTH AND ENVIRONMENTAL CONSEQUENCES OF DEPLETED URANIUM USE IN THE U.S. ARMY: TECHNICAL REPORT

AEPI

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ABSTRACT

In response to a Congressional request, the Office of the Assistant Secretary of the Army (OASA) Installations, Logistics & Environment (I,L&E) tasked the Army Environmental Policy Institute to study the health and environmental consequences of using depleted uranium (DU) on the battlefield. The study also examined the potential for remediating DU contamination, ways to reduce DU toxicity, and methods to protect the environment from the long-term consequences of DU use. Results from the study were initially presented in a *Summary Report to Congress*. Documentation and detail about the findings and conclusions of the summary report are presented in this technical report.

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The Army Environmental Policy Institute (AEPI) prepared this report under the direction of Mr. Lewis D. Walker, Deputy Assistant Secretary of the Army for Environment, Safety and Occupational Health (DASA-ESOH).

This document is a companion document to a "Summary Report to Congress" with the same title. It includes supporting information and a significant amount of technical detail not included in the summary report.

The Institute's mission is to assist the Army Secretariat in developing proactive policies and strategies to address environmental issues that may have significant future impacts on the Army. The Institute wrote this report in response to Senate Appropriations Committee Report Number 102-408.

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CHEMICAL AND MATHEMATICAL SYMBOLS

α	alpha
β	beta
γ	gamma
°C	degrees Celsius
µCi/g	microcuries per gram (one millionth of a curie)
µg	micrograms
µg/L	micrograms per Liter
µm	micron, micrometer
µR	microroentgen
Ac	actinium
Am	americium
At	astatine
Ba	barium
Bi	bismuth
C	centigrade
CaO	calcium oxide (also known as lime)
Ci	curie
cm	centimeter
cm/yr	centimeter per year
Cs	cesium
dpm	disintegrations per minute
DUF_4	depleted uranium tetrafluoride
DUF_6	depleted uranium hexafluoride
DU/g	depleted uranium per gram
E_h	redox potential
Fe(II)	ferrous iron
Fe(III)	ferric iron
$Fe_2(SO_4)_3$	ferric sulfate
ft	feet
Fr	francium
g	gram
g/cm^3	grams per cubic centimeter
H^+	hydrogen ion
H_2	hydrogen gas
H_2O	water

H_2SO_4	sulfuric acid
hr	hour
kg	kilogram
L	liter
m	meter
MeV	million electron volts
mg	milligram
MgF_2	magnesium fluoride
mg/kg	milligrams per kilogram
mg/m^3	milligrams per cubic meter
mg U/L	milligram of uranium per liter
mil	unit of measure, one-thousandth of an inch
mils/yr	one thousandth of an inch per year
mm	millimeter
MnO_2	manganese dioxide
mR	milliroentgen
mrad	millirad
mrem	millirem
NaI	sodium iodide
NH_4OH	ammonium hydroxide
$(NH_4)_2U_2O_7$	ammonium uranate
O_2	oxygen gas
Pa	protactinium
Pb	lead
pCi	picocurie
pCi/g	picocuries per gram
pCiDU/g	picocurie depleted uranium per gram
pE	electron activity (redox level)
pH	relative alkalinity of a fluid
Po	polonium
ppm	parts per million
Pu	plutonium
R	roentgen
Ra	radium
rem	roentgen-equivalent-man
Rn	radon
Sr	strontium
Tc	technetium
Th	thorium
ThO_2	thorium dioxide
Tl	thallium
U	uranium
U^0	elemental uranium

U(IV)	uranium with oxidation state 4
U(VI)	uranium with oxidation state 6
U_3O_8	uranium oxide (yellowcake)
UF_4	uranium tetrafluoride (green salt)
UF_6	uranium hexafluoride
U(O)	uranium metal, uranium with zero oxidation state
UO_2	uraninite (uranium dioxide)
UO_2^{2+}	uranyl ion
UO_2CO_3	uranyl carbonate
$UO_2 (CO_3)_2^{2-}$	uranyl dicarbonate
$UO_2 (CO_3)_3^{4-}$	uranyl tricarbonate
$UO_2 (OH)_2) \cdot H_2O$	schoepite
UO_3	uranyl oxide
$USiO_4$	uranium silicate (coffinite)
^{234}U	Uranium 234
^{235}U	Uranium 235
^{238}U	Uranium 238
wt%	weight percentage
w/w	weight/weight
yd	yard
yr	year

ACRONYMS

AAC	U.S. Army Armor Center
ACGIH	American Conference of Governmental Industrial Hygienists
ADAM	Area Denial Artillery Munition
AEHA	Army Environmental Hygiene Agency
AEPI	Army Environmental Policy Institute
AFLCR	Air Force Logistics Command Regulation
AFRRI	Armed Forces Radiobiology Research Institute
AFSCR	Air Force Systems Command Regulation
ALARA	As Low As Reasonably Achievable
AMC	Army Materiel Command
AMCCOM	Armament, Munitions and Chemical Command
AMCR	Army Materiel Command Regulation
AMSAA	Army Materiel Systems Analysis Activity
ANG	Air National Guard
ANSI	American National Standards Institute
AOAC	Armor Officer Advanced Course
AOBC	Armor Officer Basic Course
AOT	Aerojet Ordnance Tennessee, Inc.
APE	Army Peculiar Equipment
APFSDS	Armor-Piercing Fin Stabilized Discarding Sabot
APFSDS-T	Armor-Piercing Fin Stabilized Discarding Sabot with Tracer
APG	Aberdeen Proving Ground
AR	Army Regulation
ARDEC	Armament Research, Development and Engineering Center
ARL	Army Research Laboratory
ARNG	Army National Guard
ASM	Armored Systems Modernization
AST	Army Science and Technology Center
ATACS	Advanced Tank Cannon System
BEIR	Biological Effects of Ionizing Radiation [NMAB committee]
BLM	Bureau of Land Management
BNCOC	Basic Noncommissioned Officer Course
BRAC	Base Realignment and Closure [Act]
BRL	Ballistic Research Laboratory
BTD	Bomb Throwing Device
CAA	Clean Air Act
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
CFR	Code of Federal Regulations
CMS	conventional munitions systems
COCO	contractor-owned, contractor-operated

COMVAT	Combat Vehicle Armament Technology
CRDC	Chemical Research and Development Center
CX	categorical exclusion
DA	Department of the Army
DA PAM	Department of the Army pamphlet
DARCOM-R	Defense and Readiness Command Regulation
DASA-ESOTT	Deputy Assistant Secretary of the Army for Environment, Safety, and Occupational Health
DCF	Defense Consolidation Facility
D/D	decontamination/decommissioning
DESCOM	Depot Systems Command
DLAR	Defense Logistics Agency Regulation
DMWR	Depot Maintenance Work Requirement
DoD	Department of Defense
DODD	Department of Defense Directive
DODI	Department of Defense Instruction
DODM	Department of Defense Manual
DODR	Department of Defense Regulation
DOE	Department of Energy
DOT	Department of Transportation
DOTE	Department of Transportation Exception
DU	depleted uranium
DUDOSE	depleted uranium air dispersion modeling technique
DU/HE	depleted uranium/high explosive
DVA	Department of Veterans Affairs
EA	Environmental Assessment
EIA	Environmental Impact Assessment
EIS	Environmental Impact Statement
ENMOD	environmental modification [techniques]
EOD	explosive ordnance disposal
EPA	Environmental Protection Agency
ERM	Environmental Radiation Monitoring [plan]
FAR	Federal Acquisition Regulation
FLPMA	Federal Land Policy and Management Act
FM	field manual
FNSI	Finding of No Significant Impact
FORSCOM	Forces Command
FR	Federal Register
FRX	Field Response Exercise
FSTC	Foreign Science and Technology Center
FY	fiscal year
GAO	General Accounting Office
GI	gastrointestinal

GOCO	government-owned, contractor-operated
HA	heavy armor
HAZMAT	hazardous material
HDBK	handbook
HE	high explosive
HEAT	High Explosive Anti-Tank
HEPA	High Efficiency Particulate Air
HHA	Health Hazard Assessment
HQ	headquarters
IAAP	Iowa Army Ammunition Plant
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
IEP	Independent Evaluation Plans
I, L&E	Installation, Logistics and Environment
IMDG	International Maritime Dangerous Goods
JPG	Jefferson Proving Ground
JTCG/ME	Joint Technical Coordinating Group for Munitions Effectiveness
KE	kinetic energy
KEM	Kinetic Energy Missile
LANL	Los Alamos National Laboratory
LAP	load, assemble, and pack
LCC	life cycle cost
LCED	Life Cycle Environmental Document
LLRW	low-level radioactive waste
LLRWPA	Low-Level Radioactive Waste Policy Act [of 1985]
LLW	low-level waste
MAAP	Milan Army Ammunition Plant
MACOM	Major Command
MCA	Military Claims Act
MIL-SPEC	military specification
MIL-STD	military standard
MLRS	Multiple Launch Rocket System
MSC	Manufacturing Sciences Corporation
MTL	Materiels Technology Laboratory
MTMC	Military Traffic Management Command
NAVMATINST	Naval Material Instruction
NBC	nuclear, biological and chemical
NCRP	National Council on Radiation Protection and Measurements
NEPA	National Environmental Policy Act
NICP	National Inventory Control Point
NLRB	National Labor Relations Board
NMAB	National Materials Advisory Board
NMI	Nuclear Metals, Inc.

NRC	Nuclear Regulatory Commission
NRT	National Response Team
NSN	National Stock Number
NUREG	Nuclear Regulatory Commission staff-originated report
NWC	Naval Weapons Center
O&S	operations and support
OASA	Office of the Assistant Secretary of the Army
ODCSOPS	Office of the Deputy Chief of Staff for Operations and Plans
ODDR&E	Office of the Director Defense Research and Engineering
OPM	Office of Personnel Management
ORF	Operational Readiness Float
OSHA	Occupational Health and Safety Administration
OTSG	Office of the Surgeon General
PBMA	Production Base Modernization Activity
PCB	polychlorinated biphenyl
PDM	Pursuit Deterrent Munition
PEIS	Programmatic Environmental Impact Statement
PEO	Program Executive Officer
PL	public law
PM	Program Manager
PNL	Pacific Northwest Laboratory
POL	petroleum, oils and lubricants
QASAS	Quality Assurance Specialist (Ammunition Surveillance)
R&D	research and development
REDOX	reduction chemistry
RBE	relative biological effectiveness
RCRA	Resource Conservation and Recovery Act
RDT&E	research, development, testing and evaluation
RESRAD	residual radiation
RPO	Radiation Protection Officer(s)
SAC	Senate Appropriations Committee
SADA	Savanna Army Depot Activity
SB	supply bulletin
SDMP	Site Decommissioning Management Plan
SDWA	Safe Drinking Water Act
SEG	Scientific Ecology Group
SMCA	Single Manager for Conventional Ammunition
SOP	standard operating procedure
SSRA	System Safety Risk Assessment
STRAC	Standards in Training Commission
SUP	supplement
TACOM	Tank Automotive Command
TB	technical bulletin

TECOM	Test and Evaluation Command
TEMP	Test and Evaluation Master Plan
TERA	Terminal Effects Research and Analysis
TLD	thermoluminescent dosimeter
TLV	threshold limit value
TM	technical manual
TMAS	Tank Main Armament Systems
TR	technical report
TRADOC	Training and Doctrine Command
TWA	time weighted average
UK	United Kingdom
UMTRA	Uranium Mill Tailings Remedial Action
U.N.	United Nations
USA	U.S. Army
USACHPPM	U.S. Army Center for Health Promotion and Preventive Medicine
USACSTA	U.S. Army Combat Systems Test Activity
USAF	U.S. Air Force
USAR	U.S. Army Reserve
USC	U.S. Code
USFS	U.S. Forest Service
USN	U.S. Navy
UXO	unexploded ordnance
WA	tungsten (wolfram) alloy
WSMR	White Sands Missile Range
YPG	Yuma Proving Ground

EXECUTIVE SUMMARY

Background

In response to a Congressional request, the Army Environmental Policy Institute (AEPI), acting under the direction of Office of the Assistant Secretary of the Army (Installations, Logistics & Environment), conducted a study to determine:

- The health and environmental consequences of using depleted uranium (DU) on the battlefield.

- Remediation technologies that exist or might be developed to clean up DU contamination.

- Ways to reduce DU toxicity.

- How to best protect the environment from the long-term consequences of DU use.

In response to this request, AEPI assembled a team of health, environmental, legal and systems professionals. These experts conducted a literature review of scientific studies concerning depleted uranium. They also interviewed scientists, engineers and military officials, as well as soldiers involved in Operation Desert Shield / Desert Storm. Their purpose was not to verify the technical performance of DU weapon systems but to assess the health and environmental consequences associated with the use of DU. A summary report of the findings of this study, *Summary Report to Congress* (Appendix A), was prepared for Congress and made available in June 1994.

Scope of This Technical Report

This technical report, intended for scientific experts and advisors, is being published to document the sources used in preparing the *Summary Report to Congress* and to provide more detail regarding some of the physical, chemical and radiological health and environmental effects of the DU used in Army weapon systems. This technical report repeats (and in some cases, embellishes) the findings and conclusions presented in the *Summary Report to Congress*; no new findings are introduced here.

Findings

After an exhaustive review of weapon systems containing DU, AEPI concluded that the Army has done an excellent job attending to the environmental and health impacts of these systems. The following findings were first published in the *Summary Report to Congress* in a condensed form. They specifically address the four areas of concern raised in the original congressional tasking.

Health and Environmental Consequences of Battlefield Use

A battlefield may be contaminated with many dangerous substances. The impact of DU contamination on the battlefield is a new issue and is not well-defined. Relative to many other hazards, such as unexploded ordnance, the hazards from DU contamination are small.

Remediation Technologies to Clean Up DU Contamination

DU remediation technologies may involve one or more of the following processes: excavation and earth moving, physical separation, chemical separation and in-place stabilization. Very few remediation technologies

have actually been used to clean up DU-contaminated sites. The Army continues to identify and evaluate alternative remediation technologies.

Ways to Reduce DU Toxicity

No available technology can significantly change the inherent chemical and radiological toxicity of DU. These are intrinsic properties of uranium.

Protecting the Environment from Long-Term Consequences

The Army has implemented range management and DU recovery systems and is improving these systems. The Army is also developing models to better describe the environmental fate and effects of DU. DU migration on test ranges in the United States appears to be insignificant because the soil and water conditions on the ranges tend to prevent the formation of soluble DU.

Conclusions

The following conclusions, reported in the summary document and expanded in this technical report, describe additional efforts that would lead to an even higher level of health and environmental security relative to DU. However, Army environmental goals must support the Army mission, contribute to readiness and serve the collective national best interests. Thus, investment in DU management is tempered by resource realities among competing needs.

The conclusions fall into the following categories: general recommendations, those relating to test ranges and battlefields, and those relating to environmental policy.

General Conclusions

- The Army or DoD should designate a single office, independent of DU systems development or use, to improve management and control of DU health, environmental and regulatory issues.

- The Army should revise its regulations and policy documents to explicitly link DU acquisition, use, safety and health, disposal, demilitarization, and environmental management.

- The Army should determine the full life-cycle cost of DU weapon systems. This analysis must take into account not only production costs, but also demilitarization, disposal and recycling costs; facility decontamination costs; test range remediation costs; and long-term health and environmental costs.

- An Environmental Assessment (EA) is normally used to assess the incremental impact of systems at a specific site; however, within the DoD acquisition process, an EA can also be item-specific (pertaining to a specific weapon system). Use of the same term for two entirely different types of assessments could lead to an inappropriate conclusion that the requisite environmental documentation has been prepared.

Test Ranges and Battlefields

- The Army should continue to improve training programs for the wide variety of soldiers and support personnel who may come in contact with DU or DU-contaminated equipment. At a minimum, the Army should include armor, infantry, engineer, ordnance, transportation and medical personnel in this training.

- Before Desert Storm, the probability of human survival in a vehicle hit by a DU penetrator was estimated to be

quite low, but fortunately, the actual survival rate for U.S. soldiers in vehicles that sustained friendly fire DU strikes was 80 to 90 percent. For this reason, in future conflicts where either side uses DU weapons, the Army should anticipate managing patients with DU-contaminated wounds.

- The Army should continue to investigate equipment modifications and procedures that will minimize exposure to the chemical and radiological hazards of DU, including the development of: a combat-oriented document that would define protective techniques for medical and maintenance personnel; standard markings for all weapon systems containing DU; experiments and analyses to better define the risks of DU internalization to recovery and maintenance personnel; and continue to evaluate potential DU contamination in gun tubes and crew compartments from gun bore gases or flashback incidents.

Environmental Policy

- The Army should review all current environmental documentation on DU and consider preparing a programmatic Life-Cycle Environmental Document.

- The Army should encourage Congress to revise the Low-Level Radioactive Waste Policy Act allowing allocation of waste according to the value added in each phase of development, testing and fielding a weapon system. Under this approach, a proportional share of the waste generated during testing would be charged against the waste disposal capacity of the states that receive economic benefit from the process.

- The only systematic DU contamination of Army land occurs during the research, development, testing, and evaluation (RDT&E) cycle for DU ammunition. The following actions could help the Army better manage DU contamination of test ranges:

- Plan site remediation activities on Army installations to be consistent with long-term land-use goals.

- Develop a strategy to address the long-term liabilities from DU contamination.

- Fund recovery, recycling and waste disposal programs.

- Develop waste disposal options, including volume reduction, waste minimization, waste form modification and waste disposal facilities.

- Separate high-explosives ranges from new DU ranges.

- Require catch boxes on all DU ranges; maximize recovery of DU penetrators at test ranges; maximize DU recycling within the Army (DU testing will always produce wastes).

- Provide a means to ensure timely disposal of DU waste from test ranges.

• Environmentally and financially sound remediation of DU contamination on Army test ranges requires tools to conduct site assessments, apply fate and effect models, and estimate environmental risks and costs. The Army needs to:

- Expand funding of site investigations.

- Evaluate the effectiveness and cost of remediation technologies (proposed and existing).

- Evaluate the environmental fate and effects of DU on U.S. test ranges.

- Review environmental and health hazard data obtained to date to ensure that they are consistent and scientifically defensible.

- Review DU particle data from Army studies and elsewhere to determine data gaps and conduct experiments to generate the requisite data to fill these gaps.

- Develop a better understanding of DU particles generated from impacts or burning.

- Develop environmental fate and effect models to determine relative risk as a function of migration.

- The Army should be prepared to provide guidance to other governments on the health and safety risks associated with DU for affected battlefields. This guidance may include information on environmental measurement, monitoring, migration and remediation techniques.

Actions to implement the policies suggested by the findings and conclusions in this report should be weighed against the costs associated with the environmental safety and health issues presented. Decisions must be framed in the broadest context to consider whether the studies proposed have the potential to mitigate the real costs of remediation and health management as related to Army DU weapon systems.

1 INTRODUCTION

In December 1992 the Deputy Assistant Secretary of the Army (Environment, Safety and Occupational Health) tasked the Army Environmental Policy Institute (AEPI) with studying the health and environmental consequences associated with the Army's use of depleted uranium (DU). The Secretariat initiated this AEPI study in response to a request in Senate Appropriations Committee (SAC) Report Number 102-408. Congress was concerned with issues associated with Desert Storm; however, during the months between the SAC report and initiation of the study, the congressional and public awareness related to DU markedly increased. Therefore, AEPI expanded the scope of the study to consider the health and environmental effects of DU throughout its life cycle in Army weapon systems.

This report discusses DU weapon systems, including munitions, tank armor and two mines that contain small amounts of DU catalyst. Note that the DU munitions designed for the Bradley Fighting Vehicle were *not* used in Desert Storm; however, they are discussed in this report. This investigation did not consider issues associated with how other services manage and use DU; however, many of the issues discussed herein are broadly applicable and may pertain to the other services.

The authors are not weapon systems effectiveness experts. The information presented concerning effectiveness was provided by research, design, testing and evaluation (RDT&E) experts and by soldiers who used the weapon systems in Desert Storm. These comments have been included so the reader can consider the health and environmental effects in the context of the technical effectiveness of Army DU weapon systems. The Army has developed extensive data on weapon systems performance and has made informed decisions to use DU systems based upon their performance. Because this report was developed to evaluate DU

health and environmental effects, weapon systems performance data were not reviewed.

1.1 Methodology

To fulfill the task assigned by the Army Secretariat and Congress, AEPI assembled a team of health, environment, legal and systems professionals to perform a comprehensive literature search, conduct interviews, analyze the information obtained and prepare a detailed report. It would not be appropriate to address the health and environmental consequences of DU in an isolated context. Therefore, this report examines the environmental safety and health issues associated with the DU weapon systems life cycle–acquisition, testing, use and disposal.

AEPI based its study on a comprehensive review of the environmental safety and health literature available as of November 1, 1993. The authors reviewed the four previous major DU studies:

• *Medical and Environmental Evaluation of Depleted Uranium*–1974 special report of the Joint Technical Coordinating Group for Munitions Effectiveness (JTCG/ME)

• *A Hazard Evaluation of the Use of Depleted Uranium Penetrators*–1979 report of the U.S. Army Pierre Committee

• *Comparison of DU and Tungsten for Use as Kinetic Energy Penetrators*–1979 report of the National Materials Advisory Board (NMAB) of the National Academy of Science's National Research Council

• *Kinetic Energy Penetrator Long Term Strategy Study (Abridged)*– 1990 report by M. E. Danesi for the U.S. Army Armament, Munitions and Chemical Command (AMCCOM)

These reports provided a relatively complete treatise of the environmental safety and health history of the Army DU weapon

systems development program. However, it was also evident that the Army did not pursue many of the health-related studies and most of the environment-related studies recommended in these reports. To amplify and update information presented in the literature, the study team held numerous discussions with civilian experts and Department of the Army (DA) and other Department of Defense (DoD) personnel who have been involved in developing, manufacturing, testing, using and disposing of DU munitions and armor. These discussions were concluded in July of 1994.

1.2 Document Overview

Part I, which includes Chapters 2 through 4, discusses DU and how the Army uses it in peacetime and in combat. Part II begins with a brief review of the four previous major studies of DU. The remainder of Part II (Chapters 6 through 8) responds to the specific tasks assigned by Congress. The report includes a list of acronyms, a glossary of technical terms, several appendices and a complete list of references used in preparing the report.

AEPI offers the findings and conclusions in Chapter 8 to provide decision-makers a perspective to use when responding to concerns and issues involving DU. Most of the findings and conclusions restate and update information contained in the four previous major DU studies. The report commends the Army for its practices regarding DU and points out areas for improvement. It offers specific recommendations for the Army leadership to consider.

1.3 Conclusions Preview

There are significant costs associated with implementing many of the programs suggested in the conclusions of this report. When policy-makers view these costs in the context of studying problems rather than solving them, it may be easy to conclude that

the return on investment is low. This appears to be part of the reason the conclusions from the four foundation studies have not been fully implemented. This report develops each of the conclusions concerned with environmental safety and health in more detail than previous documents; furthermore, it attempts to describe ways in which studies could be undertaken to solve current and projected problems. For example, costs for remediating Jefferson Proving Ground (JPG) may approach $1.5 billion (NRC, 1994). Developing environmental migration models for JPG to identify and publicly defend the lowest-cost remediation strategy that is environmentally responsible would cost less than $10 million. Furthermore, the model could be used at other Army sites contaminated with DU. This would be both a good investment and good stewardship of public resources.

The potential for health effects from exposure to DU is real; however, it must be viewed in perspective. It is unlikely that any of the DU exposure scenarios described in this report will significantly affect the health of most personnel. In several areas, neither the scientific community nor the Army have adequate medical or exposure information to defend this assertion. It would be fiscally prudent to develop a more comprehensive understanding of exposure potential and the concomitant medical implications. When DU is indicted as a causative agent for Desert Storm illness, the Army must have sufficient data to separate fiction from reality. Without forethought and data, the financial implications of long-term disability payments and health-care costs would be excessive.

The Army needs a robust policy to ensure environmental safety and health where DU systems are concerned. Without this, the Army will be at the mercy of a proliferation of institutional forces seeking to direct the Army to spend its health and environmental resources in ways that may not serve the best interests of the Army or the nation.

Part I:
DEPLETED URANIUM AND ITS USE IN THE ARMY

Chapter 2 presents a technical discussion of the radiological and chemical properties of uranium and summarizes the life cycle of uranium and depleted uranium. Chapter 3 provides an in-depth review of the Army life cycle of DU during peacetime, from acquisition through disposal, and concludes by discussing the salient aspects of the Army's radiation protection program. Chapter 4 describes the Army's experience using DU in Operation Desert Shield/Desert Storm.

2 PROPERTIES, CHARACTERISTICS AND LIFE CYCLE OF URANIUM USED BY THE ARMY

This chapter begins by discussing the properties and characteristics of uranium, including its radioactivity and chemical behavior. It then outlines the life cycle of uranium and depleted uranium from the mining of uranium ore to the production of enriched uranium hexa-fluoride UF_6 used to produce the nuclear materials required for nuclear reactors and weapons, and depleted UF_6 (DUF_6), used to manufacture DU metal for military and civilian applications.

2.1 Properties and Characteristics

2.1.1 Forms of Uranium

Uranium, a radioactive element, is a silver-white metal in its pure form. It is a heavy metal nearly twice as dense as lead (19 grams per cubic centimeter [g/cm^3] compared with 11.4 g/cm^3).

Uranium occurs in nature in a wide variety of solid, liquid and gaseous compounds. It readily combines with other elements to form uranium oxides, silicates, carbonates and hydroxides. These compounds range from being highly mobile (soluble) to being relatively immobile (insoluble) in the environment and the human body (Erikson et al., 1993; Stokinger, 1981). Several conditions affect the formation of these compounds: the relative amounts of oxygen, moisture and acidity present; the presence of other metals alloyed with uranium; and the temperature history of the uranium solid (Erikson et al., 1993). The resultant uranium compound also depends on the original form of the uranium (alloy and mineral phase) and its interaction with environmental media

(soil, air, surface and ground water, and biota). Uranium compounds dissolve and migrate at different rates.

Uranium metal alloys are readily machinable and have metallurgical properties similar to those of many high-strength steels (Magness, 1985; NMI, undated a). Small particles of uranium metal and some uranium alloys are pyrophoric—they can ignite spontaneously in air, as a function of surface to volume ratio, and they burn rapidly at very high temperatures (Stokinger, 1981).

2.1.2 Radioactivity

The earth's crust contains three naturally occurring uranium isotopes: uranium-234 (^{234}U), uranium-235 (^{235}U) and uranium-238 (^{238}U). Each is radioactive. Isotopes of an element have essentially identical chemical and physical properties because they have the same number of protons in their atoms. Isotopes are differentiated by the number of neutrons they contain. Variation in the number of neutrons gives isotopes different radiological properties; uranium isotopes vary in their ability to undergo nuclear fission, interactions with nuclear particles, radioactive decay rates, and the types of radiation they emit upon radioactive decay. The radioactivity of isotopes can be compared using specific activity which is measured in nuclear transformations (disintegrations) per second per unit mass (e.g., in microcuries per gram (μCi/g), where a microcurie is equal to 3.700×10^4 nuclear transformations per second). While ^{234}U, ^{235}U and ^{238}U have essentially the same chemical and physical properties, the variation in the number of neutrons makes them radiologically different.

The ^{234}U and ^{235}U constitute less than 1 percent of naturally occurring uranium (see Table 2-1). The ^{234}U is a major contributor to the radioactivity of naturally occurring uranium despite its small percentage by weight because its specific activity is so high in comparison with ^{235}U and ^{238}U. The ^{238}U is the most abundant naturally occurring uranium

isotope and the least radioactive. The specific activity of uranium with the natural isotopic mix is approximately 0.7 µCi/g.

Each uranium isotope has a long half-life. Each isotope decays to produce a series of radioactive daughter products, which in turn decay to subsequent daughter products. Each step in this process emits one or more forms of ionizing radiation—alpha (α) particles, beta (β) particles and gamma (γ) rays (Coleman et al., 1983; Cross, 1991; Piesch et al., 1986; Rohloff and Heinzelmann, 1986).

Table 2-1. Components of Naturally Occurring Uranium

ISOTOPE	WEIGHT PERCENTAGE*	RADIOACTIVITY (µCi/g)	CONTRIBUTION TO RADIOACTIVITY OF URANIUM	HALF-LIFE† (YEARS)
URANIUM-234 (^{234}U)	0.0058 %	6200.0	50.4 %	2.47×10^5
URANIUM-235 (^{235}U)	0.71 %	2.2	2.3 %	7.1×10^8
URANIUM-238 (^{238}U)	99.28 %	0.33	47.3 %	4.5×10^9

* Exact weight percentages of uranium found in nature vary slightly with the source. Values shown here were reported by Eisenbud, 1987.

† Half-life is the time required for 50 percent of an unstable material to decay.

An alpha particle is a positively charged (+2) ion composed of two protons and two neutrons. Isotopes that emit only alpha particles do not pose a health risk if they are outside the body because alpha particles cannot penetrate the skin's dead layers. However, internalized alpha particles do pose a health risk. A beta particle is an electron emitted during the radioactive decay of a neutron. Beta particles can penetrate the skin, so isotopes that emit beta particles pose health risks both externally and internally. A gamma ray is a

discrete packet (quantum) of electromagnetic energy with no mass or charge. It is extremely penetrating and poses health hazards both externally and internally.

The serial decay chains presented in Figure 2-1 and Figure 2-2 show the breakdown of radioactive elements until stable isotopes of lead are reached. Stable isotopes do not decay and are, by definition, not radioactive. Since the formation of the earth's elements, sufficient time has elapsed for most natural deposits of uranium isotopes and their daughter products to be in equilibrium (i.e., their rates of formation to equal their rates of decay) (Eisenbud, 1987). The decay sequences of uranium isotopes produce several radioactive isotopes that are dangerous to plants and animals; these include radium, thorium and radon. Each daughter product migrates through the environment based on its chemical characteristics.

Isotopes with short half-lives will not migrate great distances, unless they are gaseous and near the ground surface because they decay rapidly to form other elements. The highest concentrations of daughter products generally occur in the soil, air and water where uranium concentrations are highest.

Figure 2-1. The Uranium-238 Daughter Products

(Note: E means exponent of 10. 5E8 = 5 X 10^8)

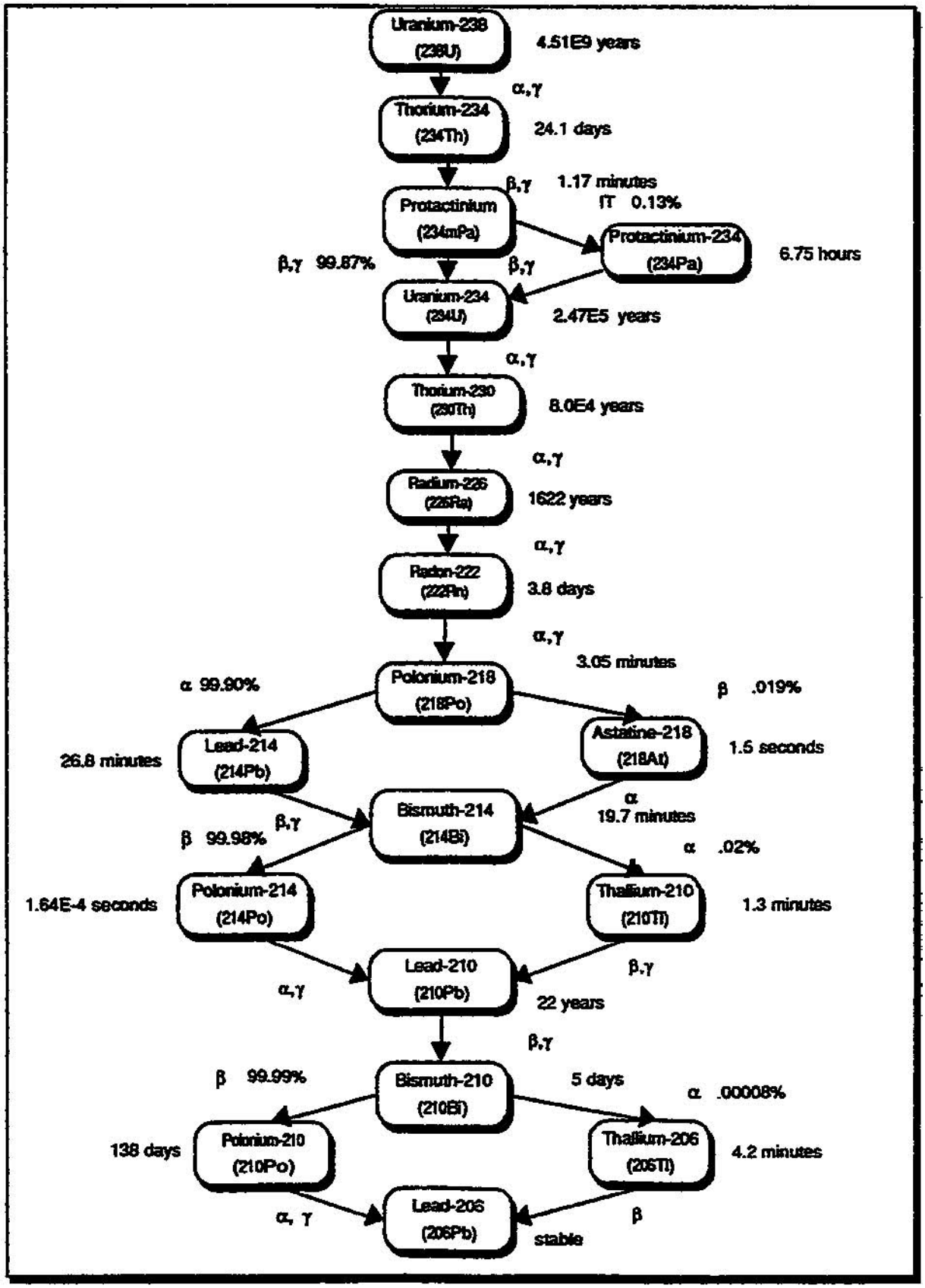
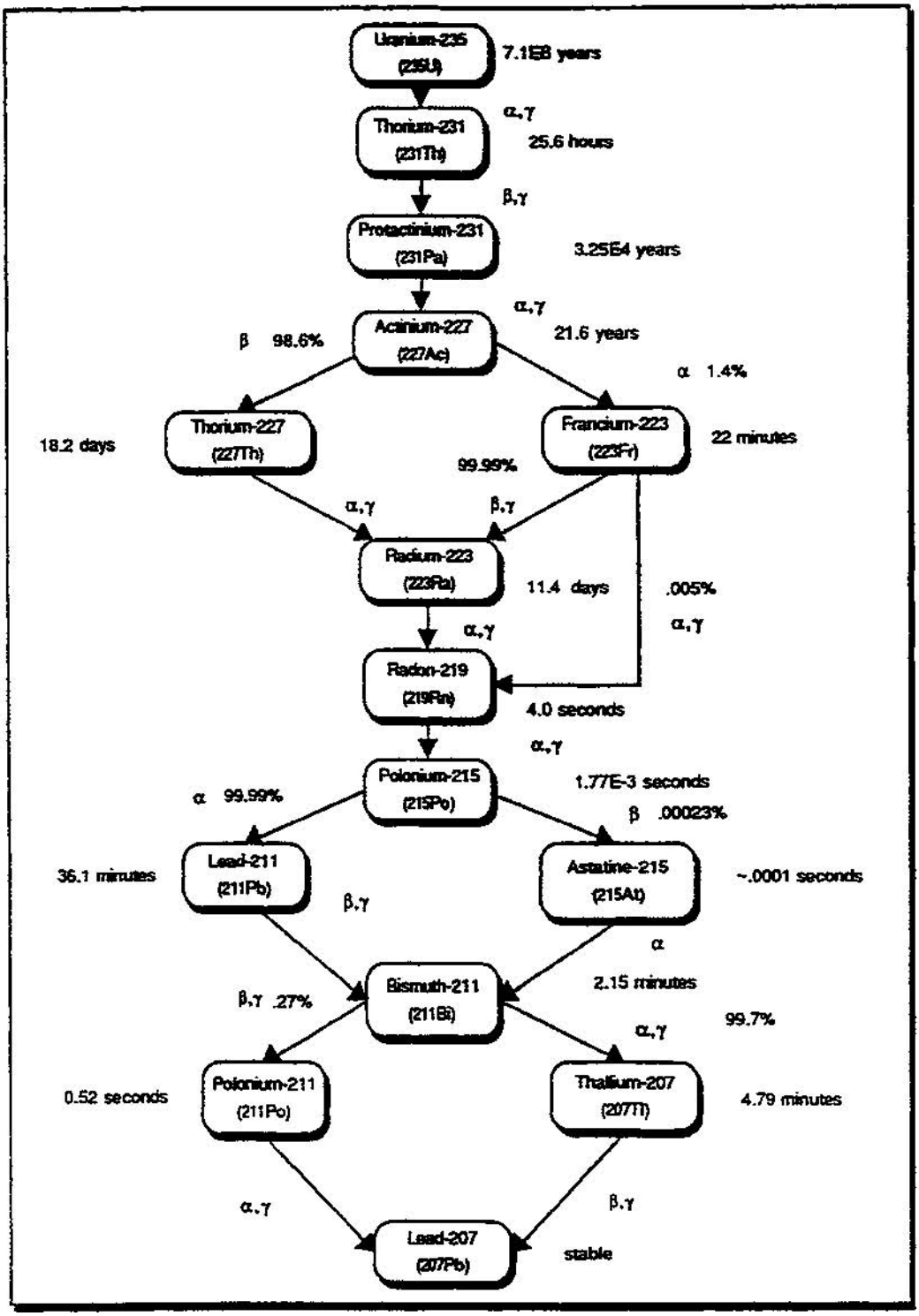


Figure 2-2. The Uranium-235 Daughter Products

(Note: E means exponent of 10. 5E8 = 5 X 10^8)



Each of the three uranium isotopes can also decay by spontaneous fission, which is so rare that it does not contribute to the daughter products formed or to the radiation emitted. The half-lives for the spontaneous fission of ^{238}U, ^{235}U and ^{234}U are approximately 8 x 10^{15} years, 4 x 10^{17} years and 2 x 10^{16} years, respectively.

As shown in Figures 2-1 and 2-2 and in Tables 2-2 and 2-3, all uranium isotopes primarily decay by alpha emission. They also emit small amounts of gamma radiation during decay. The subsequent decay of radioactive daughter products emits additional radiation. Only the first two daughter products of ^{238}U (thorium-234 and protactinium-234m) and the first daughter product from the decay of ^{235}U (thorium-231) contribute to the radioactivity of DU. Other daughter products do not accumulate in significant concentrations because stopper isotopes preclude their formation. A stopper isotope is a decay product with such a long half-life that it blocks the significant production of the remainder of isotopes in the chain. ^{234}U (half-life of 2.47×10^5 years) is the stopper isotope for ^{238}U; protactinium-231 (half-life of 3.25×10^4 years) is the stopper for ^{235}U; thorium-230 (half-life of 8.0×10^4 years) is the stopper for ^{234}U. Thus, after stopper isotopes appear, daughter products from pure uranium will not begin to appear in quantities of environmental or human health concern for more than 10,000 years. The presence of these stopper isotopes blocks production of significant quantities of the radium and radon isotopes that contribute to the radiological hazards of naturally occurring uranium deposits.

Table 2-2. The Uranium-238 Decay Series

Isotope	Half-Life	Radiation	Energy (MeV)	Percent Yield
Uranium-238 (^{238}U)	4.5 x 10^9 years	α	4.2	75.0
			4.15	23.0
		γ	0.048	23.0
Thorium-234 (^{234}Th)	24 days	β	0.192	65.0
			0.100	35.0
		γ	0.092	4.0 (doublet)
Protactinium-234m (^{234m}Pa)	1.2 minutes	β	2.29	98.0
			1.53	<1
			1.25	<1
		γ (IT)	0.39	0.13
		γ	0.817	4.0
Protactinium-234 (^{234}Pa)	6.75 hours	β	0.53	66.0
			1.13	13.0
		γ	0.100	50.0
			0.7	24.0
			0.9	70.0
Uranium-234 (^{234}U)	2.47 x 10^5 years	α	4.77	72.0
			4.72	28.0
		γ	0.093	5.0
Thorium-230 (^{230}Th)	8.0 x 10^4 years	α	4.68	76.0
			4.61	24.0
			4.51	0.35
		γ	0.068	0.6
			0.253	1.02
Radium-226 (^{226}Ra)	1622 years	α	4.78	94.3
			4.59	5.7
		γ	0.186	4.00
			0.26	0.007
Radon-222 (^{222}Rn)	3.8 days	α	5.48	100.00
		γ	0.510	0.007
Polonium-218 (^{218}Po)	3.05 minutes	α	6.0	99.98
		β	0.33	0.019

Continued…

Table 2-2. The Uranium-238 Decay Series (continued)

Isotope	Half-Life	Radiation	Energy (MeV)	Percent Yield
Lead-214 (^{214}Pb)	26.8 minutes	β	0.72	100.0
		γ	0.053	1.6
			0.242	4.0
			0.295	19.0
			0.352	36.0
Astatine-218 (^{218}At)	1.5 seconds	α	6.70	94.0
			6.65	6.0
Bismuth-214 (^{214}Bi)	19.7 minutes	β	3.26	19.0
			1.51	40.0
			1.00	23.0
			1.88	9.0
		α	5.51	0.008
			5.45	0.012
			5.27	0.001
		γ	0.609	47.0
			1.12	17.0
			1.764	17.0
Polonium-214 (^{214}Po)	1.64×10^{-4} sec	α	7.69	100.0
		γ	0.799	0.014
Thallium-210 (^{210}Tl)	1.3 minutes	β	1.9	56.0
			1.3	25.0
			2.3	19.0
		γ	0.296	80.0
			0.795	100.0
			1.31	21.0
Lead-210 (^{210}Pb)	22 years	β	0.015	81.0
			0.061	19.0
		γ	0.0465	4.0
Bismuth-210 (^{210}Bi)	5.0 days	β	1.17	99.99
		α	5.0	8×10^{-5}
Polonium-210 (^{210}Po)	138 days	α	5.3	100.0
		γ	0.80	0.0011
Thallium-206 (^{206}Tl)	4.2 minutes	β	1.51	100.0
Lead-206 (^{206}Pb)	Stable	--	--	--

Table 2-3. The Uranium-235 Decay Series

ISOTOPE	HALF-LIFE	RADIATION	ENERGY (MEV)	PERCENT YIELD
URANIUM-235 (^{235}U)	7.1 x 10^8 years	α	4.21	5.7
			4.58	8.0 (doublet)
			4.4	57.0
			4.37	18.0
		γ	0.110	2.5
			0.143	11.0
			0.163	5.0
			0.185	54.0
			0.205	5.0
			0.302	52.0
THORIUM-231 (^{231}Th)	25.6 hours	β	0.218	13.0
			0.140	40.0
			0.026	2.0
		γ	0.085	10.0 (complex)
PROTACTINIUM-231 (^{231}Pa)	3.25 x 10^4 years	α	5.00	24.0
			4.94	22.0
			5.02	23.0
			5.05	10.0
		γ	0.027	6.0
			0.29	6.0 (complex)
ACTINIUM-227 (^{227}Ac)	21.6 years	β	0.046	98.6
		α	4.95	1.4 (doublet)
		γ	0.070	0.08
THORIUM-227 (^{227}Th)	18.2 days	α	6.04	23.0
			5.98	24.0
			5.76	21.0
			5.72	14.0 (doublet)
		γ	0.050	8.0
			0.237	15.0 (complex)
			0.31	8.0 (complex)
FRANCIUM-223 (^{223}Fr)	22 minutes	β	1.15	99.99
		α	5.35	0.005
		γ	0.050	40.0
			0.080	13.0
			0.234	4.0

Continued…

Table 2-3. The Uranium-235 Decay Series (continued)

ISOTOPE	HALF-LIFE	RADIATION	ENERGY (MEV)	PERCENT YIELD
RADIUM-223 (^{223}Ra)	11.4 days	α	5.75	9.0
			5.71	54.0
			5.61	26.0
			5.54	9.0
		γ	0.149	10.0 (complex)
			0.270	10.0
			0.33	6.0
RADON-219 (^{219}Rn)	4.0 seconds	α	6.82	81.0
			6.55	11.0
			6.42	8.0
		β	0.272	9.0
			0.401	5.0
POLONIUM-215 (^{215}Po)	1.77 x 10^{-3} seconds	a	7.38	99.99
		β	--	2.3 x 10^{-4}
LEAD-211 (^{211}Pb)	36.1 minutes	β	1.36	92.0
			0.95	1.4
			0.53	6.0
		γ	0.405	3.4
			0.427	1.8
			0.832	3.4
ASTATINE-215 (^{215}At)	~10^{-4} seconds	α	8.00	100.0
BISMUTH-211 (^{211}Bi)	2.15 minutes	α	6.62	84.0
			6.28	16.0
		β	--	0.27
		γ	0.35	14.0
POLONIUM-211 (^{211}Po)	0.52 seconds	α	7.45	99.0
			6.89	0.5
		γ	0.57	0.5
			0.90	0.5
Thallium-207 (^{207}Tl)	4.79 minutes	β	1.44	100.0
		γ	0.870	0.16
LEAD-207 (^{207}Pb)	Stable	--	--	--

2.1.3 Chemical Behavior

Although the radiological properties of uranium isotopes differ considerably, their chemical behavior is essentially identical. Chemical behavior is determined by oxidation state, which is defined as the difference between the number of protons in the atom (each with a +1 charge) and the number of electrons (each with a -1 charge).

For example, U^{+6} has six more protons than electrons. The oxidation state of an element is commonly written as a parenthetical roman numeral following the symbol for the element. Thus, U(IV) and U(VI) signify uranium in its +4 and +6 oxidation states. These two states and the zero oxidation state (U^0) are the most common oxidation states for uranium. The uranium metal used in penetrators and armor is in the zero oxidation state, which is thermodynamically unstable even at low temperatures. When exposed to the environment, metallic uranium will eventually oxidize (corrode) to U(IV). In the presence of oxygen, this oxidation is shown by the following reaction, where U is elemental uranium and UO_2 is U(IV):

$$U + O_2 \leftrightarrow UO_2$$

Depending on environmental conditions, further oxidation may form U(VI), shown here as UO_2^{2+} :

$$UO_2 + 2\ H^+ + 1/2\ O_2 \leftrightarrow UO_2^{2+} + H_2O$$

Oxidation of uranium metal liberates a large amount of heat. When the uranium surface to volume ratio is high, the heat of oxidation can cause the metal to burn, hence the pyrophoric nature of uranium.

In the absence of oxygen, uranium can be oxidized by water, releasing hydrogen gas, as shown by the following reaction:

$$U + 2\ H_2O \leftrightarrow UO_2 + 2\ H_2$$

These reactions are analogous to corrosion reactions for iron. Iron metal left in the soil will corrode to ferrous iron, Fe(II), and to ferric iron (rust), Fe(III).

As with iron, microbial action can speed the corrosion of uranium. The corrosion rate is controlled by several variables, including the oxygen content, presence of water, size of the metal particles, presence of protective coatings and the salinity of the water present. With respect to DoD applications, the principal factor controlling corrosion is the size of the particles. Small particles of uranium metal, produced by abrasion and fragmentation, corrode rapidly because they have relatively large surface areas with respect to volume. Large masses of uranium metal (such as ingots), that are protected from the elements, corrode very slowly (Abbott et al., 1983). The important point is that eventually all uranium metal, U^0, will oxidize to U(IV) and U(VI).

Note that uncommon uranium oxides will form at high temperatures and pressures. These oxides are thermodynamically unstable and will quickly convert to more familiar low-temperature U(IV) and U(VI) oxides. Elder and Tinkle (1980) provide additional information on the high-temperature oxidation of uranium metal.

2.2 Life Cycle of Uranium and DU

Uranium ores are mined, milled and converted into metals and ceramics for nuclear reactors and nuclear weapons, the major uses of uranium. Figure 2-3 depicts the uranium life cycle from the mining of naturally occurring uranium to the ultimate storage and disposal of uranium and depleted uranium end products.

2.2.1 Mining

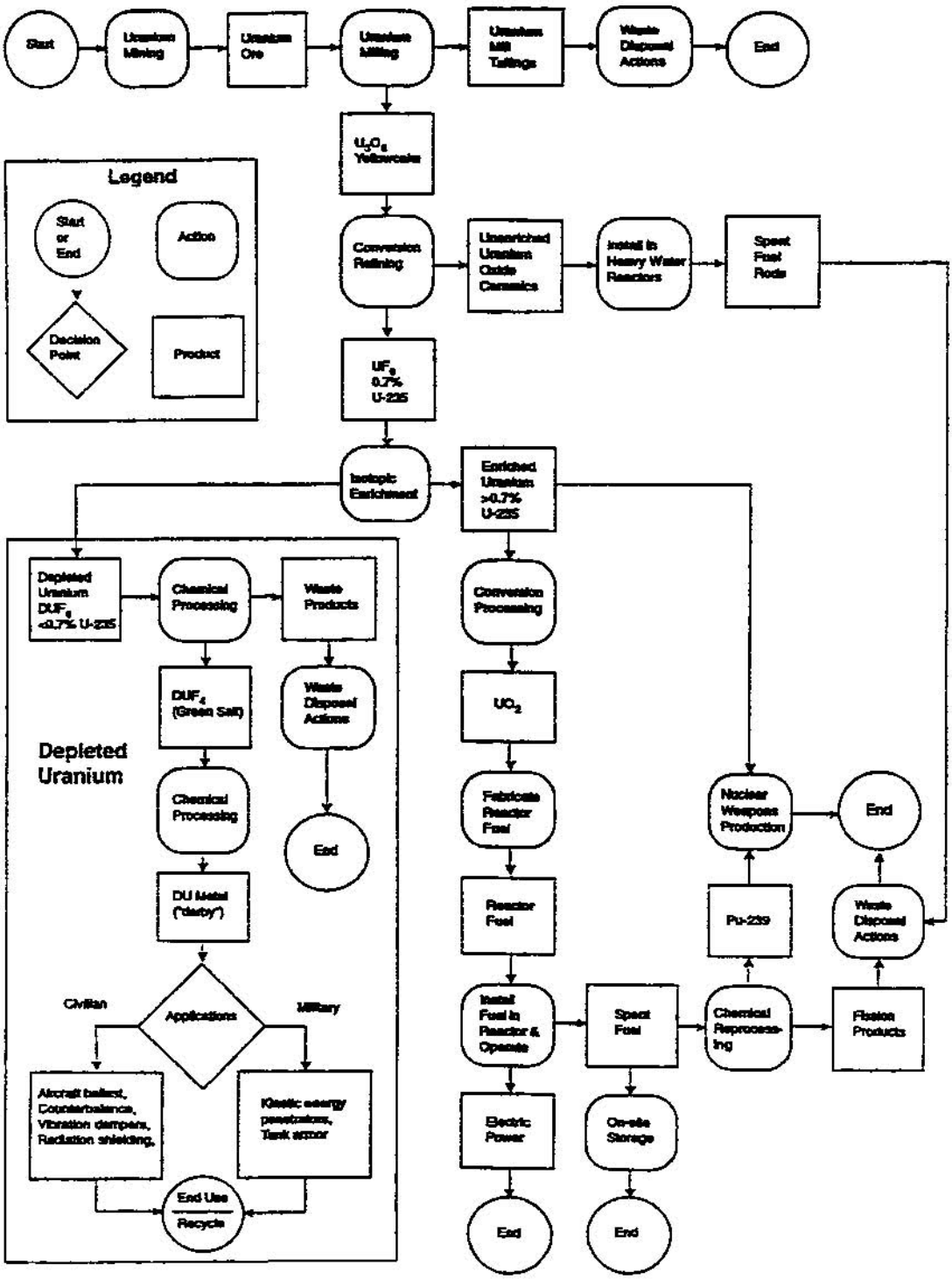
Historically, nearly all U.S. uranium has come from mines in New Mexico, Colorado, Wyoming, Utah and Arizona. The Bureau of Land Management (BLM), the U.S.

Forest Service (USFS) and the Department of Energy (DOE) are the primary regulators for exploring and uranium mining on federal public lands. Uranium mining is not subject to the licensing requirements administered by the Nuclear Regulatory Commission (NRC). DOE regulates uranium mining leases on public lands designated for its use and on certain other lands under its control (10 CFR 760 et seq). Individuals may obtain mining rights on public lands through unpatented claims, patented claims and leases.

All mining operations on federal public lands are subject to the Federal Land Policy and Management Act (FLPMA) of 1976 (Public Law [PL] 94-579), which requires mining practices that lessen mining's adverse impact on the environment (43 USC 1712c). Mining operators and owners also are subject to liability under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) and the Resource Conservation and Recovery Act (RCRA). The Environmental Protection Agency (EPA) regulates waste discharges at uranium mining operations (40 CFR 440.30 et seq).

Most U.S. uranium ore deposits are sandstone formations where uranium minerals have chemically precipitated onto the sand grains. The most common minerals are oxides such as uraninite, (UO_2), and silicates such as coffinite, ($USiO_4$ (Langmuir, 1978). Typical ore concentrations range from about 0.05 percent to 1 percent or more by mass. A uranium concentration of 0.05 percent weight/weight (w/w), or 500 milligrams per kilogram (mg/kg), corresponds to about 2 pounds of uranium in a cubic yard of ore. The price of uranium and the mining and milling costs determine the cutoff concentration of ore that is mined. Uranium producers extract uranium from both open pit and underground mines, depending on the ore's depth.

Figure 2-3. Uranium/Depleted Uranium Life Cycle



As with any mining, these procedures often pose an environmental threat. The DOE has initiated a number of major remediation efforts to clean up surface and groundwater contamination created by uranium mine tailings.

After producers extract uranium ore, mills crush it and leach the uranium from the ore with sulfuric acid (acid leach process) or soda ash (alkaline leach process). Milling extracts more than 95 percent of the uranium from ore. Dissolved uranium is recovered from solution as a precipitate called "yellowcake" (U_3O_8) by either solvent extraction or ion exchange (Merrit, 1971). The uranium in U_3O_8 has the same mix of uranium isotopes as natural uranium. U_3O_8 can be used directly in "heavy water" nuclear reactors or can be processed into UF_6 for subsequent enrichment. Heavy water nuclear reactors are designed to use natural uranium. In the United States, these reactors are only used in producing fissionable material for nuclear weapons.

Portions of washed or milled ore regarded as too poor to be processed further, called mill tailings, are pumped as a slurry onto large unlined piles. Mill tailings typically contain about 75 percent of the radioactivity of the original ore. This radioactivity comes from uranium daughter products such as radium, thorium and radon. Radon-222 is a gas and, as such, presents the greatest radiological hazard associated with mill tailings. The use of a strong acid or a strong base in the milling process also dissolves many other species present in the ore. Consequently, radioactive mill tailings frequently also have high concentrations of other potentially toxic substances such as arsenic, selenium, iron, nitrate and sulfate (Thomson and Heggen, 1983).

NRC issues licenses for refining, processing and milling uranium (10 CFR 40.1; 42 USC 2092). Congress has also written specific laws to address uranium mill tailings

sites (42 USC 7901 et seq), and the EPA administrator has issued health and environmental standards for uranium mill tailings (42 USC 2022). NRC requires remedial actions for mill tailings to ensure that radioactivity does not exceed specified levels. Remedial actions apply to the control of residual radioactive material at designated processing or depository sites and to the restoration of such sites following any use of subsurface minerals. Remedial action must be effective for at least 200 years. DOE is charged with implementing these requirements. NRC and states that pay part of the remediation cost must concur with the DOE implementation plan (40 CFR 192.00-192.30).

2.2.2 Enrichment's Byproduct: Depleted Uranium

Enrichment is an industrial process that increases the percentage of ^{235}U in the isotopic mix from approximately 0.7 percent found in nature to a content ranging from 2 percent to more than 90 percent. Various nuclear power and nuclear weapons applications require enriched uranium with a high concentration of ^{235}U by weight, as it is the only natural uranium isotope that can sustain the nuclear chain reaction the applications require. Enrichment increases the ^{235}U and ^{234}U concentration in UF_6 through a complex process based on slight differences in the atomic mass of uranium isotopes. The enriched UF_6 is then converted either to the uraninite UO_2 required for nuclear reactor applications or to the uranium metal U^0 required for nuclear weapons.

Enrichment also produces a byproduct: UF_6 that is depleted of ^{235}U and ^{234}U. This depleted DUF_6 is used to manufacture DU metal for military and civilian applications. DUF_6 is processed to produce depleted uranium tetrafluoride, DUF_4, also called "green salt." DoD contractors use green salt to produce depleted uranium metal, which is often referred to as "derby." This metal is

heat-treated and alloyed to improve its physical properties for use in kinetic energy penetrators and other weapon systems.

2.2.3 Characteristics of DU Used by DoD

NRC defines DU as uranium in which the weight percentage of the ^{235}U isotope is less than 0.711. This is slightly less than the concentration of ^{235}U in uranium ore, which is approximately 0.72 percent (10 CFR 40.4). Military Specification MIL-U-70457 stipulates that DU used by DoD must have a ^{235}U concentration of less than 0.3 percent—less than half of the fissionable ^{235}U allowed by the NRC definition of DU. DoD actually uses DU containing approximately 0.2 percent ^{235}U (Vumbaco, 1993b; Price 1980). As an artifact of the enrichment process, ^{234}U is removed from the natural isotopic mix by approximately the same percentage as ^{235}U.

Although the chemical and physical properties of natural uranium and DU are essentially identical, their radiological properties differ, as shown in Table 2-4. Three points should be noted here:

- DU may have trace amounts (about 0.003 weight percent) of ^{236}U. The ^{236}U is not a naturally occurring uranium isotope, but is sometimes present as a byproduct of nuclear fission in uranium derived from nuclear fuel (Price, 1990). The radioactivity of depleted uranium is roughly 60 percent that of natural uranium. The reduction in the ^{234}U and ^{235}U isotopes substantially lowers specific activity. The presence of trace amounts of ^{236}U does not significantly increase DU's radioactivity because the specific activity of ^{236}U (63.6 µCi/g) is only about 1 percent of the specific activity of ^{234}U (6,200 µCi/g).

- DU cannot sustain a nuclear chain reaction in conventional reactors or be used as the fuel for nuclear

weapons because of the reduced concentration of ^{235}U. The concentration of ^{235}U in naturally occurring uranium is high enough to sustain a nuclear chain reaction in heavy water nuclear reactors.

Table 2-4. Naturally Occurring Uranium Compared with the Depleted Uranium Used by DoD

Material	Components By Weight Percentage				Radioactivity † (μCi/g)
	^{234}U	^{235}U	^{236}U	^{238}U	
U* found in nature	0.0057%	0.72%	0%	99.28%	0.7
DU used by DoD	0.001%	0.20%	0.0003%	99.8%	0.4

* The weight percentages quoted for naturally occurring uranium vary slightly from source to source.

† Reported values for the radioactivity (specific activity) of depleted uranium vary depending primarily on the weight percentages of ^{234}U and ^{235}U (10 CFR 20). While the exact ratio will vary, the radioactivity of depleted uranium will always be less than that of naturally occurring uranium.

2.3 Summary

Uranium, a radioactive element, is very dense in its metallic form. Uranium ore is mined, milled and refined for use in nuclear reactors and nuclear weapons. To facilitate its use in reactors and weapons, uranium is enriched, a process that increases the weight percentage of the ^{235}U isotope. The enrichment process also produces a byproduct, uranium depleted of ^{235}U. Depleted uranium cannot sustain a nuclear reaction or be used as the fuel for nuclear weapons, but its high density and metallurgical properties make it useful in kinetic energy weapons and armor systems. Depleted uranium is roughly 60 percent as radioactive as naturally occurring uranium. The NRC definition of DU is uranium with less than 0.711 weight percentage of the ^{235}U isotope. DoD specifications require DU with a ^{235}U concentration of less than 0.3 percent. Thus, the DU used in DoD weapon contains less than half of the ^{235}U allowed by NRC.

3 THE DU LIFE CYCLE IN THE ARMY

This chapter considers general applications for DU and specific military applications in particular. It describes the regulations, policies and procedures that the Army follows in acquiring, ensuring system safety, producing, storing, transporting, demilitarizing and disposing of DU weapon systems. In addition, this chapter briefly describes the Army's radiation protection program for all phases of the DU life cycle.

3.1 Applications

During the early years (1945 to 1960) of weapons production and reactor fuel manufacturing, DU was collected and stored. Scientists and engineers later found additional military and civilian uses for DU because of its density. The material has been used in military ordnance and in medical, space, aviation, heavy equipment, and petroleum exploration applications. The U.S. military uses DU in kinetic energy penetrators, armor plate and anti-personnel mines. Other nations also use DU in civilian and military applications. Typical non-military systems that use DU include:

- Neutron detectors.
- Radiation detection and shielding for medicine and industry.
- Shielding in shipping containers for radiopharmaceuticals, other radioisotopes, and spent nuclear reactor fuel rods.
- Components of aircraft ailerons, elevators, landing gear, and rotor blades.
- Damping weights, mounting brackets, and boring bars to suppress vibration chatter during petroleum exploration.
- Counterbalance weights in radar antennae and ballast in satellites, missiles, and other craft.

3.2 Army Systems Containing DU

The Army uses alloyed DU in the 25, 105, and 120 millimeter (mm) kinetic energy cartridges. The Bradley Fighting Vehicle will use the 25 mm cartridge (not released for use as of May 1995) in its chain gun. The M1 and M60 series tanks use the 105 mm cartridge; the Army also plans to use the 105 mm in the main gun of the XM8 Armored Gun System. The M1A1 and M1A2 Abrams Tank main guns use the 120 mm cartridge. A cross section of a typical 120 mm DU round is shown in Figure 3-1. DU is used as an armor component on the M1 series heavy armor (HA) tanks. Small amounts of DU are used as an epoxy catalyst for the M86 Pursuit Deterrent Munition (PDM) and the Area Denial Artillery Munition (ADAM).

More than 50 current and former sites have been involved in the production, manufacture, development, testing and storage of DU for various DoD uses (see charts in Appendix B). As of February 1994, contractors had produced more than 1.6 million DU penetrators for tank ammunition and more than 55 million DU penetrators for small caliber (20, 25 and 30 mm) applications. More than 99 percent of the small-caliber production has been for the U.S. Air Force (30 mm GAU-8)

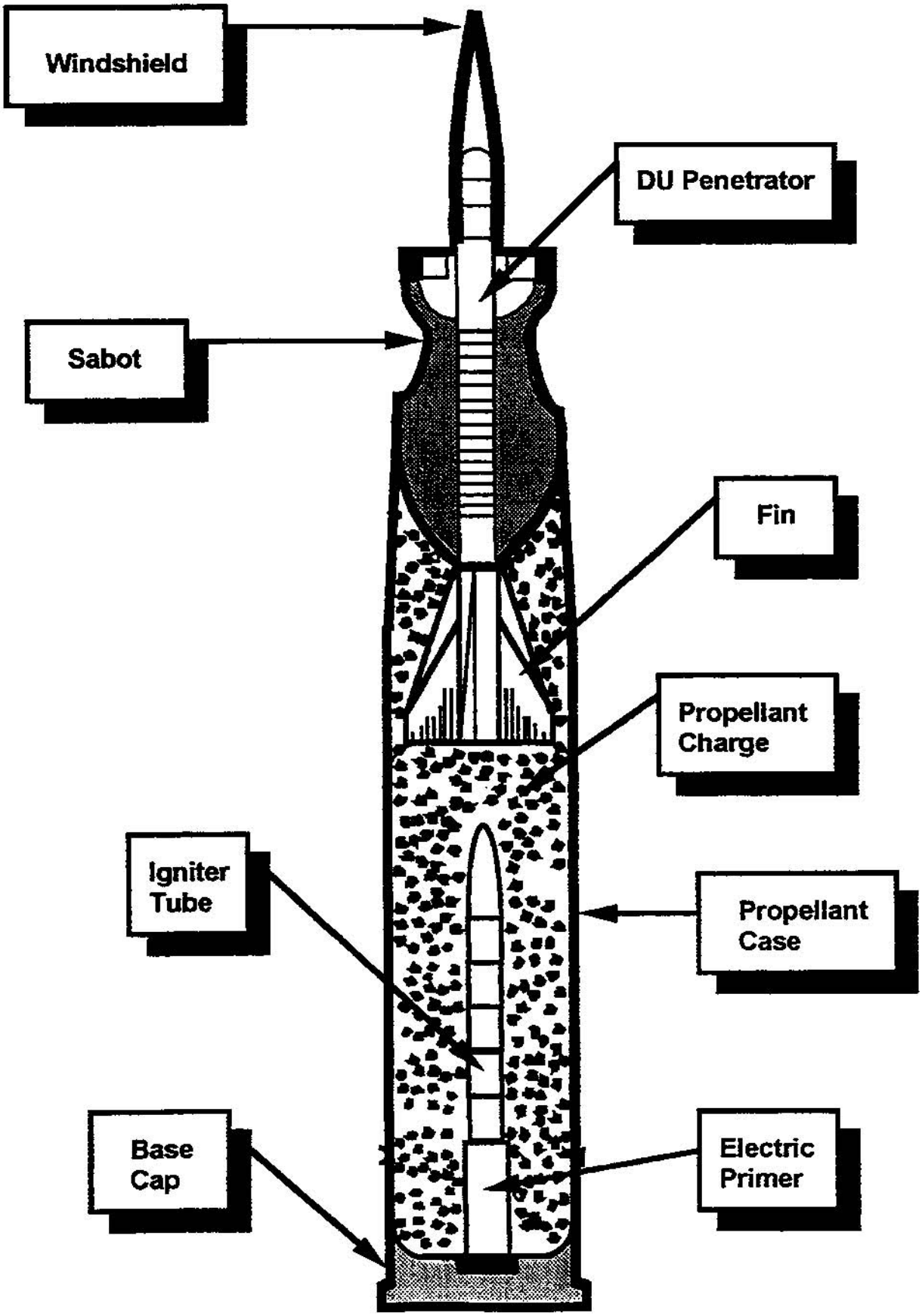
3.3 Acquisition

Three documents describe the policies and procedures of the Defense Systems Acquisition Process that the Army follows for major weapon systems:

- DoD Directive (DODD) 5000.1, *Defense Acquisition*
- DoD Instruction (DODI) 5000.2, *Defense Acquisition Management Policies and Procedures*
- DoD Manual (DODM) 5000.2-M, *Defense Acquisition Management Documentation and Reports*

Beginning with Phase 0 of the Defense Systems Acquisition Process (concept exploration and definition), the project manager for a weapon system must assess the potential environmental effects of each concept (see Figure 3-2). In addition, at each milestone the project manager must

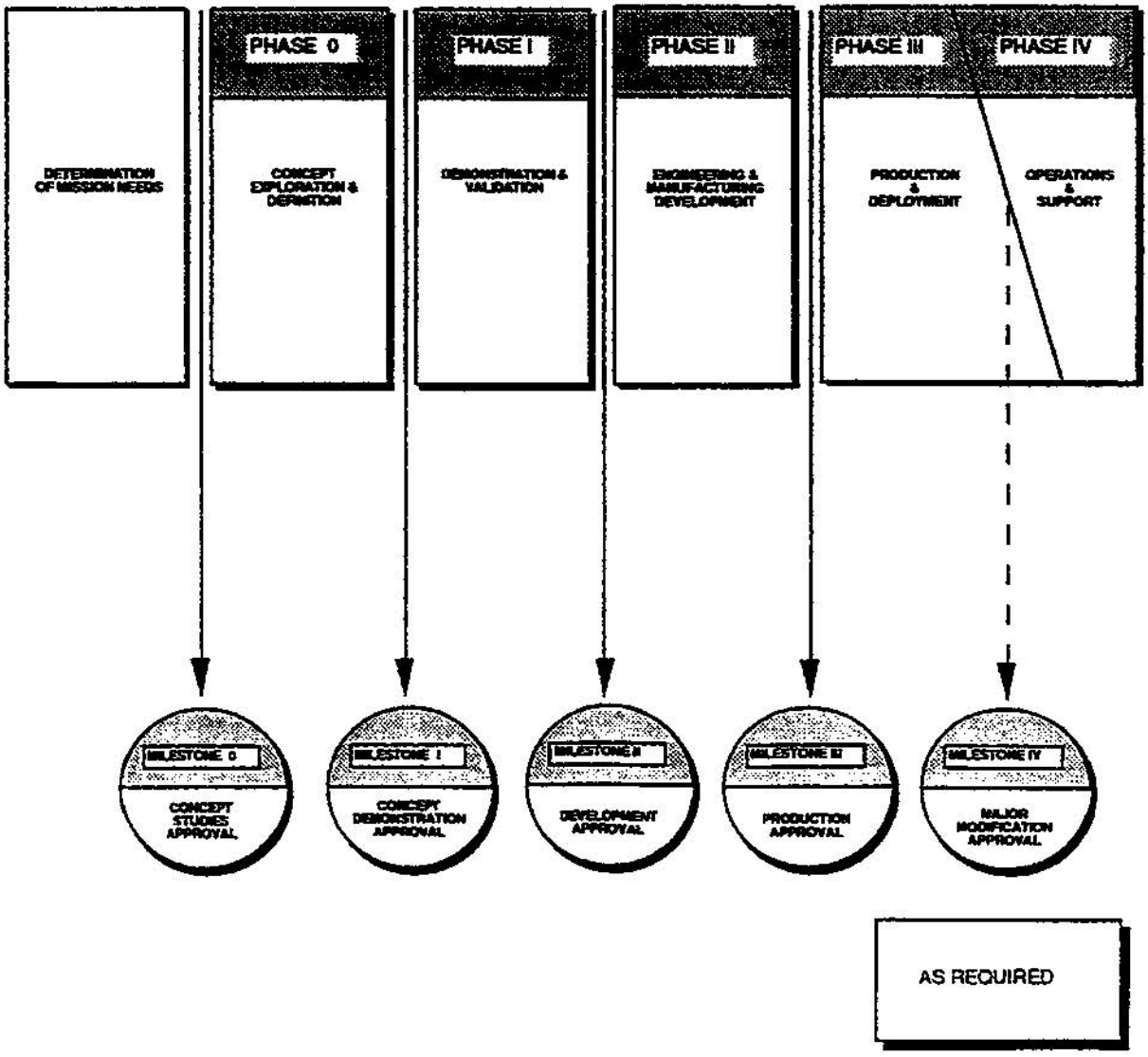
Figure 3-1 120 mm DU Round



document the system safety, health hazards, and hazardous material (HAZMAT) that the system design cannot mitigate or eliminate. For a system to proceed past Milestone I into the Demonstration and Validation phase, the milestone decision authority must confirm that the "potential environmental consequences of the most promising alternatives have been analyzed and appropriate mitigation measures have been identified" (42 U.S. Code 4321-4335; 40 Code of Federal Regulations 1500-1508).

The DODI 5000.2, Part 6, Section I, System Safety, Health Hazards and Environmental Impacts, details the environmental and system safety considerations that the project manager must apply to the life cycle of a weapon system during acquisition.

Figure 3-2 Defense Systems Acquisition Process



The Army essentially follows the life cycle evaluation process described in the National Environmental Policy Act (NEPA). These findings are documented in Annex E of the Integrated Program Summary for a proposed system at each milestone. The NEPA process, as incorporated into the Defense Systems Acquisition Process, also requires a complete system life cycle analysis of the environmental consequences of a proposed system and the actions the PM or system user can take to mitigate any environmental impacts. This process starts with the inception of the system and is carried through to the system's disposal from inventory. The NEPA requires the PM to use a systematic interdisciplinary approach to determine the environmental consequences of using a proposed system. Similar evaluations are made under Military Standard-882C (MIL-STD-882C), *System Safety Program Requirements,* for personnel and equipment safety during system use, as well as under individual service regulations.

As Figure 3-2 shows, the Defense Systems Acquisition Process begins with determining mission needs and continues through system operations and support. It includes field testing to ensure compliance with requirements. However, except for system effectiveness, it does not address the results of a system's use. For example, it may not address test range cleanup after a system is used.

Army Regulation 70-1 (AR 70-1), *Army Acquisition Policy–Research, Development, and Acquisition,* implements DODI 5000.2 and assigns responsibilities to DA commands to support environmental quality and system safety activities. When DoD is acquiring a new system, the Program Executive Officer (PEO), Program Manager (PM), or major command (MACOM) designee is responsible for the required environmental analyses, system safety evaluations, and health hazards evaluations. DA Pamphlet 70-1 (DA Pam 70-1), *Materiel Acquisition Handbook* (revised February 1994), provides procedural guidance. Other

regulations detail subordinate command procedures for safety, health and environmental analyses of weapon systems. AR 200-2, *Environmental Effects of Army Actions*, governs NEPA implementation; it establishes policy, procedures and responsibilities for assessing the environmental effects of Army actions. The following sections of AR 200-2 relate to AR 70-1 and the DoD documents previously described:

1-5, b. Environmental considerations will be integrated into the decisionmaking process to ensure that—

(1) Major decision points are designated for principal programs and proposals likely to have a significant effect on the quality of the human environment, while providing for the NEPA process to coincide with these decision points.

(2) Relevant environmental documents, comments, and responses accompany the proposal through the existing Army review and the decisionmaking process. The Army will integrate NEPA requirements with other planning and environmental review procedures required by law or Army practice so that review of environmental considerations is concurrent rather than consecutive.

2-1, b. The NEPA process includes the systematic examination of possible and probable environmental consequences of implementing a proposed action. To be effective, integration of the NEPA process with other Army project planning will occur at the earliest possible time to ensure—

(1) Planning and decisionmaking reflect environmental values….

2-1, c. To achieve these actions, all Army decisionmaking that may have an impact on the human environment will use a systematic, interdisciplinary approach that ensures the integrated use of the natural and social sciences, planning, and the environmental design arts. (PL 91-190; Sec. 102 (2) (A)). This

approach allows timely identification of environmental effects and values in sufficient detail for evaluation concurrently with economic, technical, and mission-related analyses at the earliest possible step in the decision process….

2-2, a. The types of projects or actions to evaluate for environmental impact include….

(2) New management and operational concepts and programs in areas such as logistics, research, development, test and evaluation, procurement, and personnel assignment.

(5) Requests for a Nuclear Regulatory Commission license (new, renewal, or amendment) or an Army radiation authorization….

2-2, b. In addition to the above, certain activities supported by the Army... require proper environmental documentation: …

(3) Request for approval to use or store materials, radiation sources, hazardous and toxic material, or wastes on Army land….

2-6, c(2). An example would be the assessment of a proposed major weapon system program. Development of an overall programmatic EIS [Environmental Impact Statement] or EA [Environmental Assessment] for the life cycle of the system is recommended. Tiered EAs and EISs, as appropriate, would evaluate specific subphases such as testing, production, development, use, and ultimate disposal.

3-1, f. *Life cycle environmental document (LCED)*. The LCED is intended to be a programmatic assessment that addresses the known and reasonably foreseeable environmental impacts of a proposed item/system during all phases of development, production, use, and ultimate disposal of the item/system. The LCED may be in the form of an EA or an EIS, and must be supplemented to address additional significant environmental impacts as conditions change. The LCED will be prepared by the

DA proponent/developer (or program manager) and is most frequently used within the materiel research, development, and acquisition community.

AR 200-2 does not adequately identify the environmental responsibilities of PEOs and PMs in systems acquisition. However, if AR 200-2 and AR 70-1 are examined together and if the environmental phraseology in AR 70-1 is interpreted to mean NEPA documentation, PEOs and PMs do seem to have environmental responsibilities. (Requirements in these regulations are not cross-referenced.)

Table 3-1 lists the environmental documentation for Army systems involving DU.

3.4 System Safety

The DODD 5000.1, *Defense Acquisition* and MIL-STD-882C, *System Safety Program Requirements*, provide requirements for developing and implementing a system safety program to identify hazards and improve design requirements and management controls. They are intended to eliminate hazards or to reduce risk to an acceptable level. The MIL-STD-882C applies to all DoD systems and facilities and to every activity in the system life cycle.

The AR 385-16, *System Safety Engineering and Management*, implements the DoD system safety policy. It prescribes policies and procedures and identifies responsibilities to ensure that the Army identifies hazards in its systems and facilities and properly manages their risks. Army policy requires commands to implement system safety engineering and management responsibilities throughout the life cycle of each Army system and to document each system's safety. This documentation is reviewed at all Materiel Decision Reviews. Army policy under AR 385-16 is that the health hazard assessment required by AR 40-10, *Health Hazard Assessment Program (HHA) in Support of the Army Materiel Acquisition Decision Process* must be considered. Safety analyses and safety and health verifications are key to the Army's system safety effort.

Table 3-1. Environmental Documentation for Army Systems With DU

REFERENCE ID	TITLE
ARDEC, 1991a	Addendum to M86 PDM Life Cycle Environmental Assessment
CCAC, 1988a	EA, Cartridge, 120 mm APFSDS-T, M829
CCAC, 1988b	Record of Environmental Consideration, Cartridge, 120 mm, APFSDS-T, M829E1
CCAC, 1989	Record of Environmental Consideration, 120 mm, APFSDS-T, M829E2
CCAC, 1990a	Environmental Documentation for Evaluation of the EX35 105 mm Gun System Utilizing Cartridge 105 mm, APFSDS-T, M833
CCAC, 1990 b	Life-Cycle Environmental Assessment, Cartridge, 25 mm APFSDS-T M919
CCAC, 1991	Life-Cycle Environmental Assessment, Cartridge, 105 mm APFSDS-T, M900E1
LCWSL, 1978	Cartridge, 105 M2, APFSDS-T, XM774 and Cartridge, 105 mm, APFSDS-T, M735E1 Environmental Impact Assessment, Production Phase
PBMA, 1994	Life-Cycle Environmental Assessment, Cartridge, 120 mm APFSDS-T, M829A2
PM ABRAMS, 1977	Original M1 Environmental Impact Assessments (EIA)
PM ABRAMS, 1981	Abrams Tank System Environmental Assessment: Revised EIA
PM ABRAMS, 1986	EIA Block II Program
PM ABRAMS, 1988	Environmental Assessment of the Abrams Heavy Armor System
PM ABRAMS, 1990	Abrams Tank System Environmental Assessment M1A2 EA

Note: The Project Manager's Office for the M1A2 heavy armor tank is updating environmental documentation for the tank and will complete it before fielding the weapon (Hyder, 1993; Cannon, 1993). The authors did not find any plans to generate environmental documentation for the ADAM mine.

The HHA Program is designed to identify, evaluate, and eliminate or control health hazards associated with weapon system management. AR-40-10 states that the Army cannot compromise health protection criteria and standards without formally documenting the risks. For each system, the PM must submit health hazard data to the Army's Office of the Surgeon General (OTSG) for assessment. In addition, the U.S. Army Test and Evaluation Command (TECOM) confirms the safety of each fielded munition system. TECOM is an Army Materiel Command (AMC) subordinate command chartered as the independent safety evaluator for weapon systems.

The MIL-STD-882C, AR 385-16, and AR 40-10 normally require TECOM to do substantial testing of components and systems of a new design. Since World War I, the Army has developed a series of standard tests for tanks and

ammunition; new tests are created as needed. Where appropriate, a program manager may initiate tests on weapons at extreme and ambient temperatures (-25^{o} to 120^{o} F). Health and safety testing includes tests for toxic fumes, blast overpressure, radiation, rough handling, vibration, metal fatigue (where component failure could hurt personnel), excess charge, and human factors. Before the Army uses any weapon, TECOM reviews data from tests involving personnel and, if satisfied, issues a safety release. Various reports document the results and conclusions of safety and environmental testing. The reports include the safety confirmation issued by TECOM, the HHA issued by the U.S. Army Center for Health Promotion and Preventive Medicine (USACHPPM) and reviewed by the AMC Command Surgeon, and the Safety and Health Data Sheet issued by the developer. The reports identify all known residual hazards and categorize them according to severity and frequency. The developer then must either eliminate the hazards or reduce the risks to an acceptable level.

A program manager must request approval of each residual hazard in a weapon system being proposed for acceptance. The PM is required to write a formal System Safety Risk Assessment (SSRA) to document the acceptance of any risk that exceeds the criteria for low risk.

Radiological hazards are a particular concern during the development of DU munitions and armor. The Army measures radiation from a cartridge, a cartridge in its shipping container, a pallet of rounds, and a vehicle fully loaded with DU munitions. It then performs hazard classification tests, including burn tests of a pallet, to determine exclusion zones and appropriate cleanup procedures for a fire or explosion (Fliszar, 1993b). Other tests include tank burn tests and hard impact tests of a penetrator on an armored target. If a new DU weapon is similar to an existing DU weapon, some of the tests are not repeated.

After testing the developmental item and measuring radiation, the developers, including the Armament, Munitions and Chemical Command (AMCCOM), compare the data with established radiation system safety protocols, that include current NRC standards. The developers then prepare a request for a license amendment that AMCCOM submits to the NRC. The NRC passes judgment on the proposed license amendment. The Army does not release items to the soldier in the field in peacetime without an approved NRC amendment.

The AMCCOM assumes responsibility for monitoring the weapon system in the field and serves as the central point of contact on DU questions and issues from the field. It conducts periodic wipe tests on ammunition to detect the formation of uranium oxides (Buckrop, 1993). The Army Materiel Systems Analysis Activity (AMSAA) also periodically tests ammunition and armor.

3.5 Production

3.5.1 General Controls

Except for exploration and mining, NRC has primary responsibility for regulating the use and disposal of uranium. Additional groups that oversee various aspects of the uranium life cycle include DoD, DOE, EPA, the Department of Transportation (DOT), BLM, USFS and 28 “agreement states.”

Section 274 of the Atomic Energy Act of 1954 allows a state to assume regulatory authority over nuclear sources and byproducts if its governor signs a formal agreement with NRC. For a state to assume this authority and become an “agreement state,” its governor must certify that the state’s regulatory program can protect the public health and safety. Furthermore, NRC is required to “perform an independent evaluation and to make a finding that the State’s program is adequate from a health and safety standpoint and is compatible with the Commission’s regulatory program”

(57 Federal Register 22495-01). The NRC reviews the licensing and regulatory actions of "agreement states" to ensure continuing compatibility with NRC regulations (56 FR 66457-02). Federal facilities in "agreement states," however, are regulated by NRC's regional licensing program and not by the states [10 CFR 40.5(b)(2)].

The NRC has issued a general license authorizing limited transfer and use of DU by commercial and industrial firms; research, educational and medical institutions; and federal, state and local government agencies. These entities are allowed to use and transfer no more than 15 pounds of DU at a time. The yearly limit is 150 pounds (10 CFR 40.22). Fifteen pounds of DU is about the size of a 12-ounce soft drink can. The license does not authorize metallurgical processing or machining of uranium. The NRC requires anyone possessing more than 15 pounds of DU, except DOE or DOE prime contractors, to have an individual license (10 CFR 40.22). Therefore, DA contractors must obtain an NRC or "agreement state" license to machine DU into munitions.

When DU is used solely because of its high density, the user only needs to register with NRC and dispose of the DU by returning it to a licensed disposal site. For example, when DU is used as a counterweight in an airplane, missile or helicopter, the user is exempt from source material licensing regulations (10 CFR 40.13).

NEPA provides the means to ensure protection of the environment (40 CFR 1500-1508). Federal agencies are required to comply with the act and use it as a decision tool in actions that will protect, restore or enhance the environment. The AR 200-2, *Environmental Effects of Army Actions*, implements NEPA. AR 200-2, paragraphs 2-2a(5) and 2-2b(3), requires the Army custodian who manages the use or storage of radioactive

materials on Army property to assess environmental impacts for new NRC licenses, renewals or amendments.

3.5.2 Procurement Procedures

An AMC subordinate command, such as AMCCOM or the Tank Automotive Command (TACOM), uses a Material and Services Order to procure DUF_6 from DOE for a specific weapons program. DOE ships cylinders of DUF_6 to a designated, licensed commercial company. The company converts the DUF_6 to DUF_4, an intermediate product, and then converts DUF_4 into depleted uranium metal (CMI, undated; DOE, 1993). Army contractors, licensed by NRC or an "agreement state," process, alloy, form, and machine the metal. The NRC, EPA, "agreement states" and Army regulations control health and environmental management in this phase of the Army DU life cycle.

3.5.3 Manufacture of DU Components

Army contractors manufacture penetrators from DU metal at contractor-owned, contractor-operated (COCO) facilities. The NRC and "agreement states" license these contractors to possess and store DU and to produce munitions components from it. A typical contractor license would permit a company to receive DUF_6 from DOE; transport it to a manufacturing facility; process it into DUF_4 and DU metal products; and sell material containing DU to an authorized buyer (DOE, 1993).

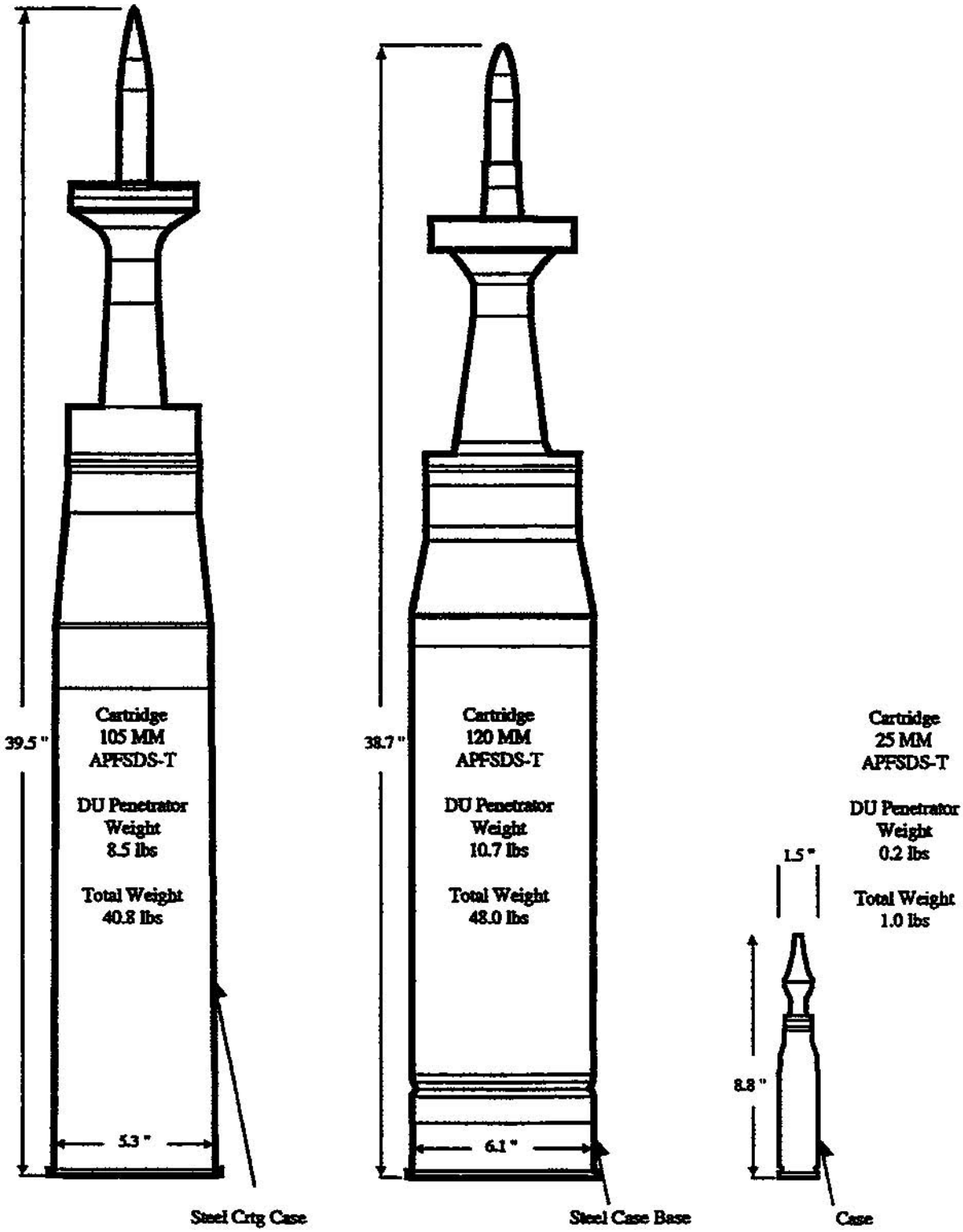
Licensees must ensure that workers' internal and external exposure to DU is consistent with standards in 10 CFR 20. Procedures vary with each license. License representatives from NRC and "agreement states" periodically inspect workplaces and records to ensure compliance with license provisions and appropriate state and federal regulations. To prevent environmental contamination outside a facility, 10 CFR 20 also requires

compliance for releases into the air and water. Some licensees design an ERM plan to document compliance.

Aerojet Ordnance Tennessee, Inc., (AOT) of Jonesborough, Tenn., and Nuclear Metals, Inc., (NMI) of Concord, Mass., are licensed to produce DU penetrators (Hickman, 1993; Vumbaco, 1993a). The Manufacturing Sciences Corporation (MSC) of Oak Ridge, Tenn., produces DU castings, bar stock, sheet and plate (Liby, 1993).

The M919 25 mm DU round is produced exclusively by Olin Ordnance in Marion, Il.; the rounds were originally produced by Aerojet Manufacturing of Chino, Calif., while the M774, M833 and M900 (105 mm) penetrators and the M829, M829A1 and M829A2 (120 mm) penetrators have been made by both AOT and NMI (Hickman, 1993). Figure 3-3 shows 105, 120 and 25 mm cartridges that contain DU penetrators. The penetrators are produced under subcontract to a government prime ammunition production contractor (usually Alliant Tech Systems of Edina, Minn., or Olin Ordnance of St. Petersburg, Fla.). The prime contractor then contracts for the metal parts manufacturing and projectile assembly with Olin Ordnance of Red Lion, Pa.; Chamberlain Manufacturing of Waterloo, Iowa; or National Manufacturing Corporation of St. Louis, Mo. Two government owned, contractor-operated (GOCO) plants load, assemble and pack (LAP) the complete tank rounds: the Milan Army Ammunition Plant (MAAP) of Milan, Tenn., operated by Martin Marietta Ordnance Systems, Inc. and the Iowa Army Ammunition Plant (IAAP) of Middletown, Iowa, operated by Mason & Hanger - Silas Mason Company, Inc. (Van Dorn, 1993; Vumbaco, 1993a; Crumpler, 1993; Hickman, 1993). Aerojet performs LAP for the 25 mm DU rounds. Each facility operates under its own license.

Figure 3-3. Cartridges that Contain DU Penetrators



The NMI and AOT are involved with all DU processes (conversion, reduction, casting, metal forming, machining, etc.) (NMI, undated a, undated b). Their licenses require radiation safety programs, including a thorough annual medical workup for all employees exposed to radiation on the job. The companies also periodically perform bioassay monitoring (whole body counting and analysis of uranium in the urine) to measure the amount of radioactive material deposited in the lungs and kidneys of workers. Each of these monitoring practices helps assure compliance with regulatory requirements and with the philosophy to keep risk As Low As Reasonably Achievable (ALARA).

When NMI and AOT work for the Army using DU, they submit employee radiation exposure information to the Army in a quarterly report as a contract deliverable.

NMI also produces cast billets that are used to make armor for the M1A1 Heavy Armor tank. During development of the M1A1 armor system, MSC also produced cast billets. The DOE fabricates them into DU armor at its Special Manufacturing Capability Site at Idaho Falls, which is operated by Babcock and Wilcox Idaho, Inc. The Lima Tank Plant in Lima, Ohio, operated by the Land Systems Division of the General Dynamics Corporation, installs the DU armor on the tanks and covers it with homogeneous rolled steel armor (McGuire, 1993a, 1993b, 1993c, 1993d; Liby, 1993).

Alliant Tech Systems, Inc., manufactures the M86 PDM and ADAM at the Twin Cities Army Ammunition Plant in New Brighton, Minn. Very small quantities of DU serve as a catalyst in an epoxy molding compound that forms the body of these two mines. Each 206-gram mine contains approximately 0.101 g of DU. Based on the weight percent of DU within the molding compound, the mines are exempt from NRC licensing (10 CFR 40.13). In a

survey of radioactivity that Alliant Tech Systems, Inc., conducted in 1983, observed readings were well below NRC requirements for an unrestricted work area (DA, 1991).

In an effort to minimize DU waste generated in the manufacturing process, the Army has funded several processes that reduce DU waste generated during DU penetrator production. AOT has a program that uses magnesium as a reducing agent to convert DUF_4 to DU metal. This process generates a magnesium fluoride (MgF_2) waste stream contaminated with DU. Historically, the MgF_2 waste stream has been classified as a radioactive waste requiring disposal as such. AOT has developed a process to recover DU contamination from the waste stream so that MgF_2 is no longer considered an NRC-regulated waste. The Army has procured the license rights for DoD, DOE and their contractors to use this process (NMI, 1991; AOT, 1993).

3.6 Army Licenses

The Army has 14 NRC licenses to possess DU. Twelve of these are for developing, testing and deploying munitions and armor containing DU. Several contractors are also licensed to use DU at Army ammunition plants, firing ranges and other locations. No license is held at the DA or MACOM level for using DU in munitions or armor. Instead, NRC issues Army licenses to the individual user or manager of a system containing DU. The licenses are site- and mission-specific. In accordance with AR 200-2, all sites must document the environmental impact of using or storing DU. Some of the AMC subordinate commands or activities that are licensed to use or store DU munitions or armor hold more than one license. A discussion of each Army licensee follows.

3.6.1 Test and Evaluation Command

TECOM is responsible for testing all Army materiel, including DU munitions and armor. It has four test centers individually licensed to use DU: U.S. Army Combat Systems Test Activity, Jefferson Proving Ground, Yuma Proving Ground and White Sands Missile Range (WSMR). The WSMR does not test DU munitions or armor and is not discussed further in this report. Each TECOM test center has an environmental monitoring program and has a document addressing the environmental impacts as required by AR 200-2. TECOM has contracted Los Alamos National Laboratory (LANL) to study the long-term fate of DU at Aberdeen Proving Ground (APG) and YPG. This investigation is designed to determine if DU migrates within or out of impact areas and, if so, what effect it has on the environment and affected populations. LANL can use information from the study to infer the health and environmental effects of DU on these ranges. LANL published a draft report from the study in late May 1995.

3.6.2 U.S. Army Combat Systems Test Activity

USACSTA, formerly the Material Test Directorate of APG, is licensed to test DU munitions and armor at APG. Systems tested there include the Bradley Fighting Vehicle, the Abrams Tank and the Tank Main Armament Systems (TMAS). In munitions testing, various sizes of rounds are fired against soft targets (plywood, plastic mesh, cloth) and hard targets (armor, steel). USACSTA conducted all testing on outdoor ranges until 1979, when NRC prohibited destructive testing that released airborne radioactive material to unrestricted areas. To accommodate this ruling, USACSTA moved hard target testing indoors so it could contain the DU particles this testing produces. In soft-target testing, DU penetrators

remain intact or break into large fragments (see Figure 3-4). Soft-target testing creates relatively few aerosol particles and is conducted on open test ranges at APG and YPG.

As of December 1992, USACSTA had used about 92,554 kilograms (kg) of DU in soft-target testing. Before 1989, personnel recovered 21 percent of the DU fired at soft targets during periodic downrange sweeps. However, these sweeps exposed personnel to hazardous unexploded ordnance (UXO). In 1989, USACSTA installed catch boxes to limit the spread of DU contamination and to reduce personnel exposure to UXO (see Figure 3-5). These sand-filled three-sided enclosures capture about 85 percent of the DU munitions fired (Oxenberg and Davis, 1993).

USACSTA has two enclosed hard target test ranges for DU: the Bomb Throwing Device (BTD) Range (Figure 3-6) and the Superbox at Ford's Farm (Figure 3-7). In the Superbox, USACSTA can fire DU munitions against a fully loaded tank equipped with DU armor.

Figure 3-4. Intact and Broken DU Penetrators

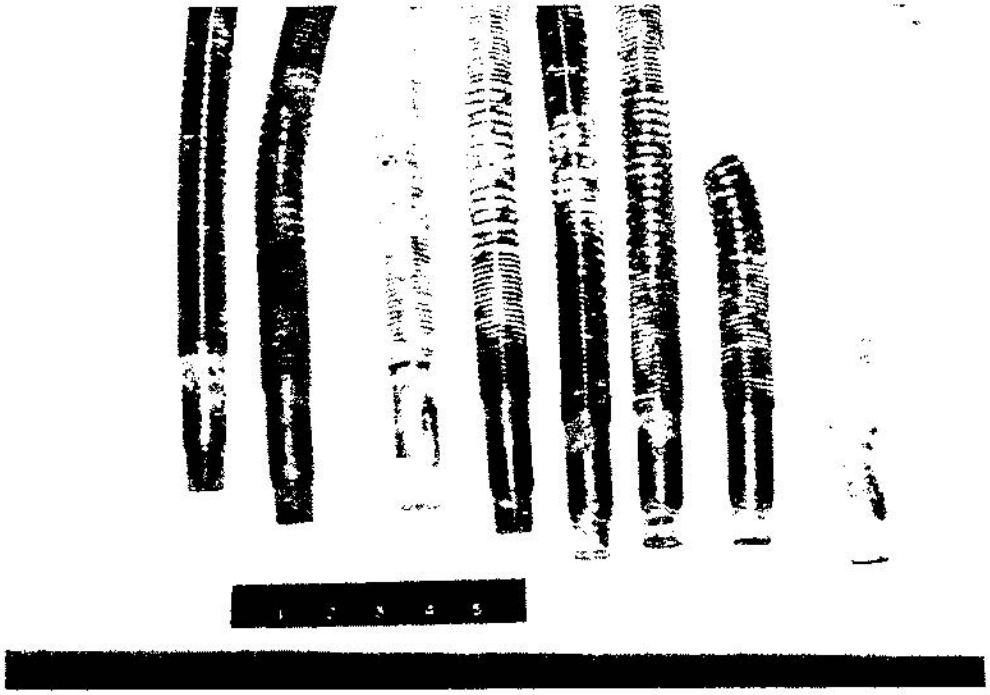


Figure 3-5. Catch Box at USACSTA

Figure 3-6. Bomb Throwing Device Range

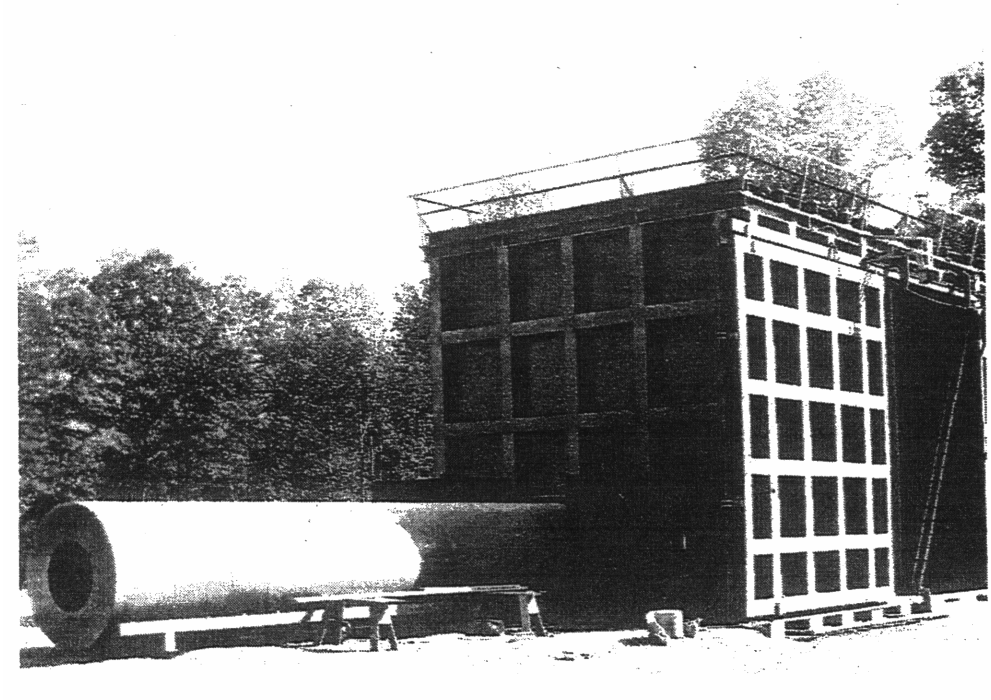
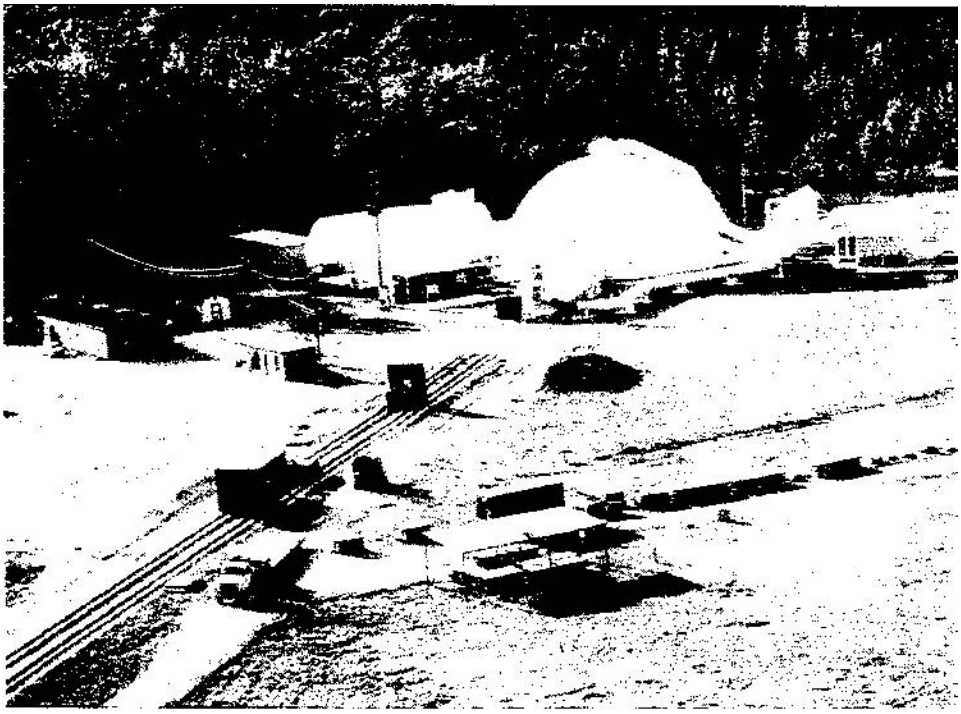


Figure 3-7. Superbox at Ford's Farm



DU-contaminated targets are disassembled in an enclosure at Ford's Farm. This structure was built in 1980 for hard-target testing and used for test firing until 1985. Disassembly must be done in an enclosure because cutting targets can release DU fragments and aerosols. The enclosure has air ventilation and filtration systems to ensure that the quality of exhaust air meets NRC standards (10 CFR 20). Real-time aerosol monitors sample respirable particles and display aerosol concentrations in aerosol mass per unit volume of air ($\mu g/m^3$). Measurements are conservative because the monitors measure all airborne substances (including dust, water, etc.) as DU. In accordance with 10 CFR 20, employees must wear respirators and protective clothing to minimize exposure when airborne particulates are detected.

USACSTA has a facility at BTD Range to decontaminate armor plate for recycling (Figure 3-8). USACSTA and ARL-Aberdeen have minimized

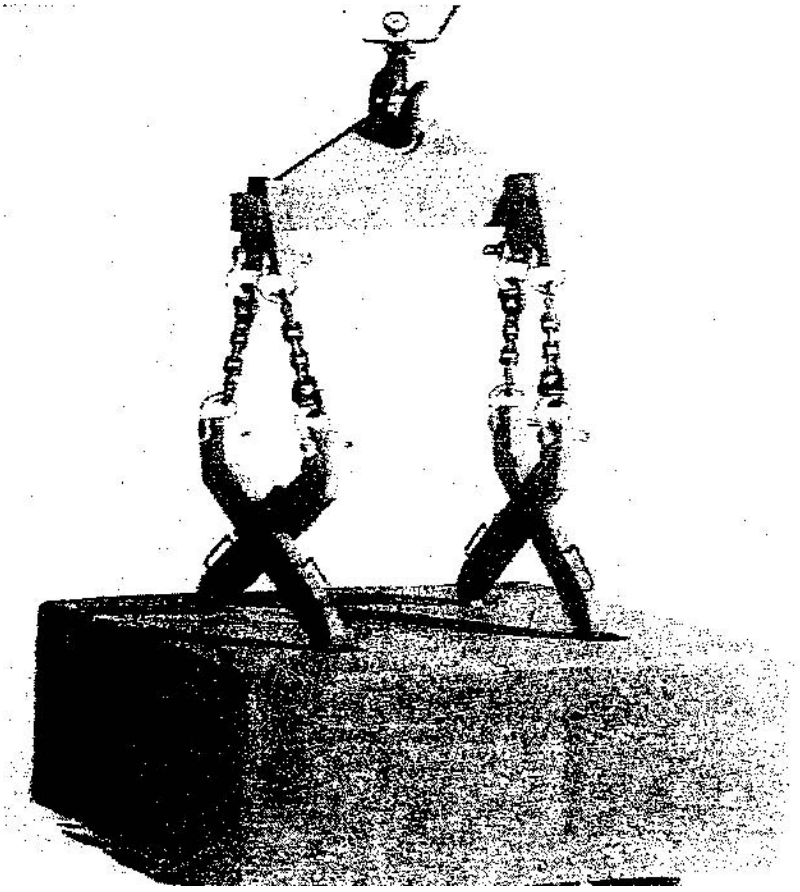
Figure 3-8. Decontamination Facility at BTD Range

radioactive waste production by recycling decontaminated and contaminated armor plate. USACSTA transferred 3,000 tons of contaminated armor plate to LANL in 1986 and 1987 for use as radiation shielding. However, holes and uneven surfaces in the plates reduced the shielding efficiency by about 25 percent compared with new armor plate. Therefore, in 1991, USACSTA contracted Scientific Ecology Group (SEG) to process 1,400 tons of contaminated plate into uniform blocks for DOE to use as radiation shielding (Figure 3-9). AMCCOM has since contracted SEG to process APG's stockpile of plate (produced by USACSTA and ARL-Aberdeen) into additional shielding blocks for DOE.

Since 1979, USACSTA has had an active ERM plan to detect possible DU migration to the environment. USACSTA continues to improve and enhance this ERM plan. USACSTA has an EA and a Finding of No Significant Impact (FNSI) addressing all DU operations at APG.

APG has contracted LANL to design a single ERM plan to address all radioisotope use by tenant activities, such as USACSTA and ARL-Aberdeen. APG expects to implement the new ERM plan in FY96 (Ebinger, 1992a).

Figure 3-9. Uniform Shielding Block



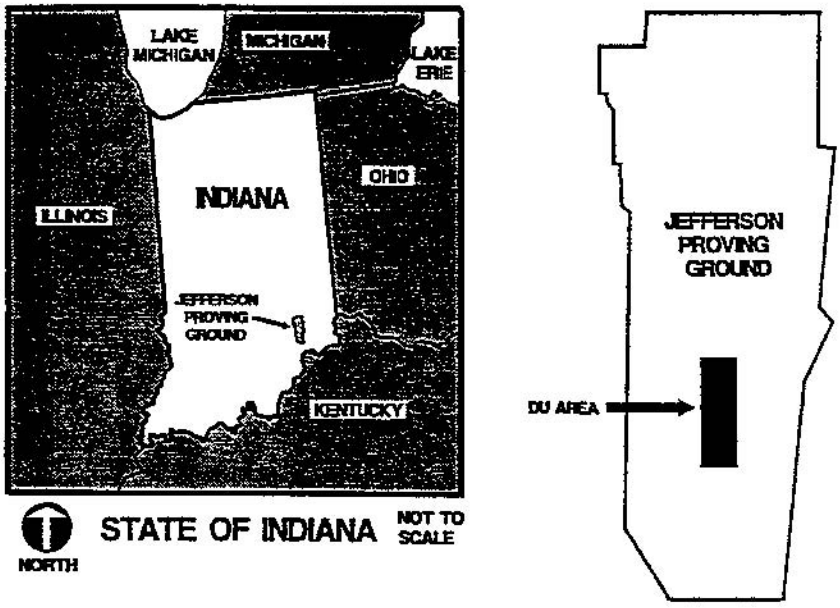
3.6.3 Jefferson Proving Ground

JPG conducted production acceptance testing of DU munitions against soft targets from March 1984 to May 1994 (NRC, 1991b). Figure 3-10 shows the location of JPG near Madison, Ind. From March 1984 to December 1992, JPG tested 90,832 kg of DU. It recovered 21,872 kg or 24 percent of the amount fired (Oxenberg and Davis, 1993). JPG shipped recovered penetrators to the manufacturer for recycling. The Army plans to close JPG in FY95 as part

of Base Realignment and Closure (BRAC) and to transfer its DU test mission to YPG. JPG did not install catch boxes, because base closure procedures prevent the construction of new facilities.

Before firing DU on the range, JPG conducted an environmental baseline study as part of an environmental assessment. JPG has also taken samples from the test range twice yearly since 1983. As a result of the EA, JPG filed a FNSI for the DU activities.

Figure 3-10. Jefferson Proving Ground



To safely remediate the DU-contaminated areas of the JPG ranges, the Army will have to strip several feet of soil to ensure the simultaneous removal of UXO. This action will facilitate soil erosion, thereby increasing the potential for DU-contaminated soil to migrate to previously clean areas. Range remediation must consider the safety issue of UXO on the range from unrelated testing of high explosive rounds.

LANL has been contracted to develop a risk assessment to evaluate alternative decommissioning strategies that will comply with current NRC requirements. TECOM is preparing a proposal to have the impact area characterized for radiation exposure and radioactivity levels. JPG will use the risk assessment, site characterization and decommissioning plan in developing remediation plans for the site (10 CFR 40.36).

The range at JPG, under existing NRC guidance, can not be released for unrestricted use unless it meets an NRC 35 picocurie (pCi) DU per gram (DU/g) of soil standard. However, the Army and NRC, using information from the LANL risk assessment (Ebinger, 1991a and Ebinger, 1993b) and elsewhere, are negotiating to develop an approach that minimizes the overall environmental impact of both the radioactive and UXO contaminants on the JPG range. JPG requested that NRC terminate its license without decommissioning the impact area to unrestricted use criteria. All buildings and firing sites were surveyed and decontaminated as required. These buildings and sites are awaiting NRC's confirming survey. The NRC is writing an EIS that considers in-place closure of the impact area as a wildlife refuge managed by the U. S. Fish and Wildlife.

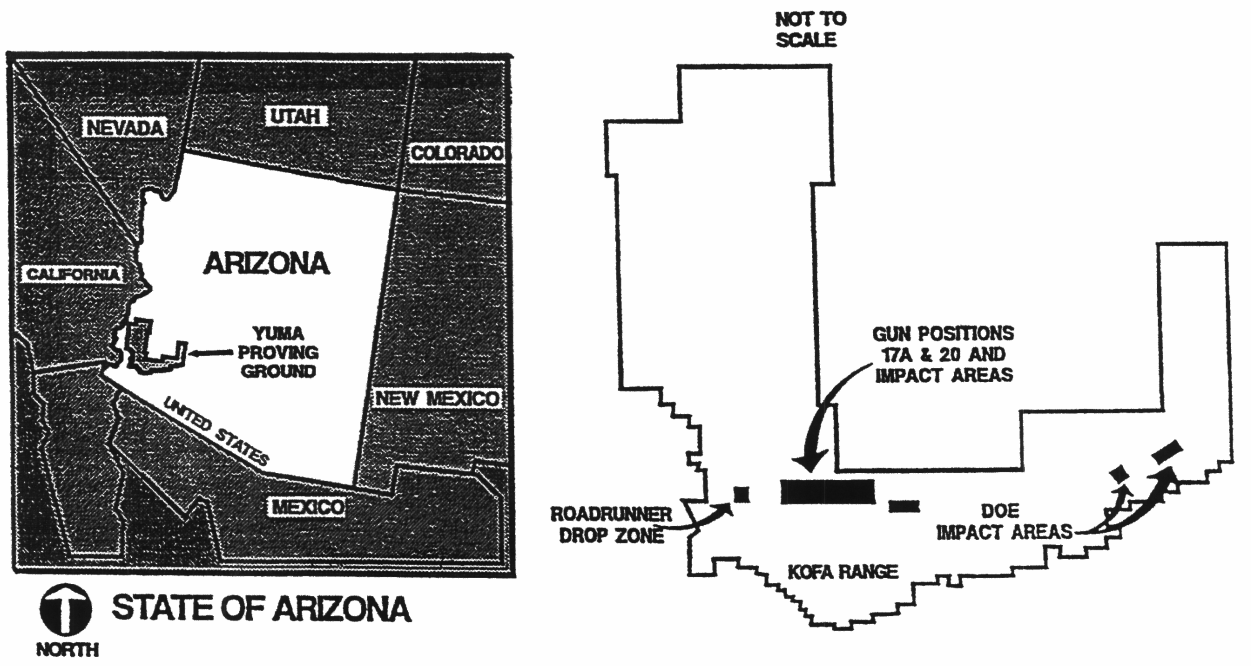
3.6.4 Yuma Proving Ground

YPG in Arizona, shown in Figure 3-11, began testing DU research and development (R&D) munitions against soft targets at gun positions 17A and 20 in 1982 (NRC, 1992e). YPG fired 38,590 kg and recovered 18,852 kg of DU during the first 10 years of operation. Catch boxes have not been built at Yuma because approximately 50 percent of the DU is already recovered. Initial estimates did not suggest that catch boxes would offer a significant improvement. However, USACSTA data have shown that catch boxes typically retain more than 85 percent of DU munitions fired at APG. Given these new data, YPG has scheduled construction of a catch box at gun position 17 to

support the transfer of JPG's mission. If the workload requires continued operations at gun position 20, YPG plans to build a catch box at that position, also.

YPG has an EA addressing the environmental impact of testing at gun positions 17 and 20. YPG also has an ERM plan and collects soil samples twice a year and sediment samples after major rainstorms. Sample data do not indicate migration out of the impact areas. YPG has contracted LANL to develop a new ERM plan that would better assess the potential for DU migration (Ebinger, 1992b).

Figure 3-11. Yuma Proving Ground



3.6.5 Army Research Laboratory

The Army Research Laboratory is licensed for DU at Watertown, Mass., and at APG.

ARL-Watertown

ARL-Watertown was formerly the Materiels Technology Laboratory (MTL) and the Materiel and Mechanics Research Center. The NRC licensed MTL to research and develop alloys and to explore military applications of DU. It was authorized to smelt, machine, cut and cast DU when developing alloys and shapes. MTL's mission ended in the late 1980s. ARL-Watertown is scheduled to be closed as part of BRAC and is presently licensed only to decontaminate and decommission its facilities and to store radioactive material until disposal. The cost for decontaminating and decommissioning ARL-Watertown is 72 million dollars. ARL-Watertown has asked USACHPPM to verify decontamination before NRC, the Commonwealth of Massachusetts and EPA will conduct the final survey. ARL-Watertown must assure these regulators of decontamination before NRC will terminate the license.

ARL-Aberdeen

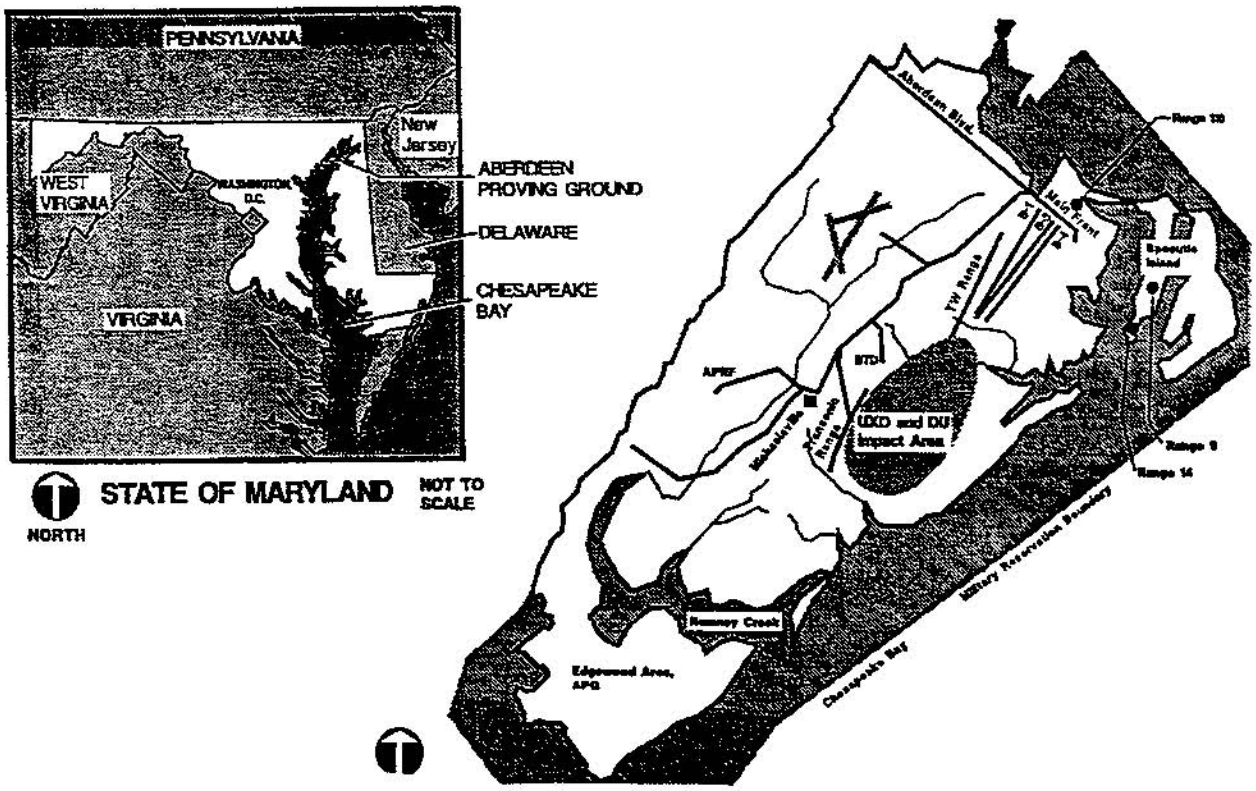
The NRC has licensed ARL-Aberdeen, formerly the Ballistic Research Laboratory (BRL), to research and develop DU penetrators and armor for the Project Managers of the Bradley, Abrams, and TMAS. The ARL-Aberdeen has conducted DU experiments since the Army's early use of DU in the 1950s. It is authorized to fire various sizes of munitions against hard targets in enclosed facilities at APG and at other temporary U.S. sites. (ARL-Aberdeen stopped open-air firing at APG in 1979.) It is also licensed to machine and cut targets containing DU and to decontaminate armor plate by liquid abrasive blasting (high pressure water mixed with an abrasive).

ARL-Aberdeen decontaminated the Aberdeen Transonic Range (an outdoor test range used before 1979). It packaged the principal waste, DU-contaminated sand, as radioactive waste and stored it at APG. The APG radioactive waste manager plans to dispose of the sand at a burial site operated by Envirocare of Utah, Inc., of Clive, Utah but is awaiting approval from AMCCOM, the Army's radioactive waste manager. The Aberdeen Transonic Range has not yet been surveyed, certified and released.

ARL-Aberdeen operates three enclosed hard target facilities at Ranges 9, 14 and 110 (Figure 3-12). ARL-Aberdeen monitors personnel exposure and environmental releases from the ventilation systems at these facilities and uses the highest measurements of DU-contaminated particles to calculate the time that personnel can safely remain in a range without exceeding personal exposure limits.

Hard target testing generates much low-level radioactive waste (LLRW) as contaminated filters, armor plate, and debris from target assembly. ARL-Aberdeen has aggressively worked to reduce this waste by compacting and shredding filters and by decontaminating armor plate. It removes contaminated areas around penetration points in these plates using liquid abrasive blasting. This process is more effective and produces fewer incidental waste products (such as acid) than the electropolishing process, which ARL-Aberdeen used before 1989.

Figure 3-12. Aberdeen Proving Ground



ARL-Aberdeen has an EA that addresses its various DU operations at APG and an ERM plan that evaluates the potential migration of DU to soil, surface water, air and vegetation (ARL, 1989, 1990). As confirmed by the ERM and area surveys, the enclosures contain the airborne contaminants and contaminated water from washing targets. Based on the EA and on sampling data from the ERM plan, ARL-Aberdeen published an FNSI that addressed three alternatives: no testing, testing at another location, and continued use of the existing enclosed firing ranges. ARL-Aberdeen considered the last option acceptable because the use of DU at APG had no significant environmental effects.

3.6.6 Watervliet Arsenal

Watervliet Arsenal, N.Y., has also studied various uses of DU in munitions. The arsenal no longer conducts DU research or uses DU. The site still contains

contaminated equipment, therefore, maintains its NRC license. This site will be decommissioned when the Army has met all cleanup criteria (NRC, 1993a).

3.6.7 Armament Research, Development and Engineering Center (ARDEC)

The NRC has licensed the ARDEC at Picatinny Arsenal, N.J., to use DU to research and develop munitions and armor for the Project Managers of the TMAS, Bradley and Abrams. The license authorizes ARDEC to machine, cut and fabricate DU. ARDEC is also authorized for indoor hard impact testing of small caliber DU munitions, but it has not tested any since 1985. DU is only used in indoor areas that are routinely surveyed for contamination. ARDEC stopped firing DU munitions outdoors in the early 1960s. ARDEC did not develop an ERM plan for this facility because it considered pathways to the environment to be insignificant. Because the DU operations at ARDEC predate AR 200-2, no environmental documents accompany the NRC license that specifically address the use of DU. ARDEC has a contractor preparing these documents to bring it into compliance with AR 200-2 (Fliszar, 1993a, 1994c).

3.6.8 AMCCOM

The AMCCOM has two NRC licenses: one authorizing it to use standardized DU sources for instrument calibration and one authorizing fielding of DU munitions (NRC, 1991a, 1992d). The second license authorizes AMCCOM to ship, store and receive DU munitions at Sierra Army Depot in Herlong, Calif.; Seneca Army Depot in Romulus, N.Y.; Hawthorne Army Depot in Hawthorne, Nev.; Letterkenny Army Depot in Chambersburg, Pa.; and temporary locations at Army installations and Marine Corps bases anywhere in the U.S. This license is limited to type-classified munitions that have NRC approval, such as the 105 mm M774, M833 and M900; the 120 mm M829 and M829A1; the 25 mm PGU-20/U series;

and the Air Force's 30 mm GAU-8. In the past, the Navy used the 25 mm PGU-20 round but has phased it out of use. The license does not cover storing, shipping, receiving or firing R&D munitions. Licenses granted to contractors and to Army Research, Development, Testing and Evaluation (RDT&E) activities must cover these R&D munitions.

AMCCOM is responsible for decontaminating the Lake City Army Ammunition Plant in Independence, Mo., which tested DU in the 1960s. The NRC licensed the Remington Arms Company to operate this plant. When the operating contractor changed from Remington Arms to Olin Ordnance, AMCCOM was required to assume licensing responsibility because Olin was not prepared to assume license responsibility for past operations not affiliated with its contract requirements.

3.6.9 Depots and Depot Activities Licensed for DU

Savanna, Sierra and Tooele Army Depots and the Seneca Army Depot Activity are individually licensed to store, transport, inspect and perform minor maintenance on DU munitions. Savanna, Sierra and Tooele are licensed to demilitarize 30 mm GAU-8 DU munitions, although only Savanna has performed these operations. As of February 1994, Seneca was awaiting approval to conduct the same operations. Environmental documentation required in AR 200-2 to specifically address the impact of DU at these locations had not been prepared by the depots as of June 1994 (Davis, K., 1993; NRC, 1990a; Scott, 1993).

3.6.10 Tank Automotive Command

TACOM is licensed to transport, store and receive DU-armored tanks at Army installations anywhere in the U.S. and to assemble DU armor onto tanks at the Lima Army Tank Plant in Lima, Ohio. TACOM is not licensed to maintain or repair the tanks' DU armor. Chem-Nuclear Systems is licensed to do this maintenance and repair and

to decontaminate tanks at the Defense Consolidation Facility (DCF) in Snelling, S.C. (McGuire, 1993e). As discussed further in Chapter 4, DCF is processing the DU-contaminated tanks and Bradleys from Operation Desert Shield and Desert Storm (McGuire, 1993f).

3.6.11 Army Contractors

Several contractors are licensed to load, to assemble and pack and to fabricate and test DU ammunition at Army or non-government sites. Alliant Tech Systems, Inc., and Olin Ordnance test DU munitions at the Energetic Material Research and Technology Center in Socorro, N.M. (formerly the Terminal Effects Research and Analysis (TERA) Facility). Alliant Tech Systems conducted open air testing of DU munitions for the Army at the Naval Weapons Center (NWC) in China Lake, Calif., from 1979 to 1989. The Army has completed remediation at NWC that meets NRC and California criteria. Alliant Tech Systems is also authorized to fabricate DU munitions at the Twin Cities Army Ammunition Plant in Minnesota (NRC, 1992a). The General Electric Company is licensed to test DU munitions at the Ethan Allen Firing Range in Burlington, Vt. The Army has stopped using the Twin Cities Army Ammunition Plant and the Ethan Allen Firing Range for DU operations; the contractors are decommissioning these sites according to the terms of their contracts.

3.7 DU Ammo Storage

The Army stores DU ammunition at depots and installations. Figure 3-13 outlines the policies and procedures that pertain to the handling, storage and use of DU.

Large caliber (120 mm) M829 series rounds are factory-packed in individual, waterproof metal containers that interlock into pallets holding either 25 or 30 rounds (Figure 3-14) (Hooker and Hadlock, 1986). The

105 mm rounds are packaged in either metal or fiber containers. Metal containers are interlocked into 30-container pallets. Fiber containers are packed with two rounds per wooden box, either 15 or 20 boxes per pallet (Bratlett et al., 1979). Medium caliber rounds (25 mm), such as M919 ammunition, are stored belted, 15 rounds per belt, two belts per can, with 27 cans per pallet (Hadlock and Parkhurst, 1990).

Figure 3-13. Policies and Procedures Pertaining to DU Handling, Storage and Use

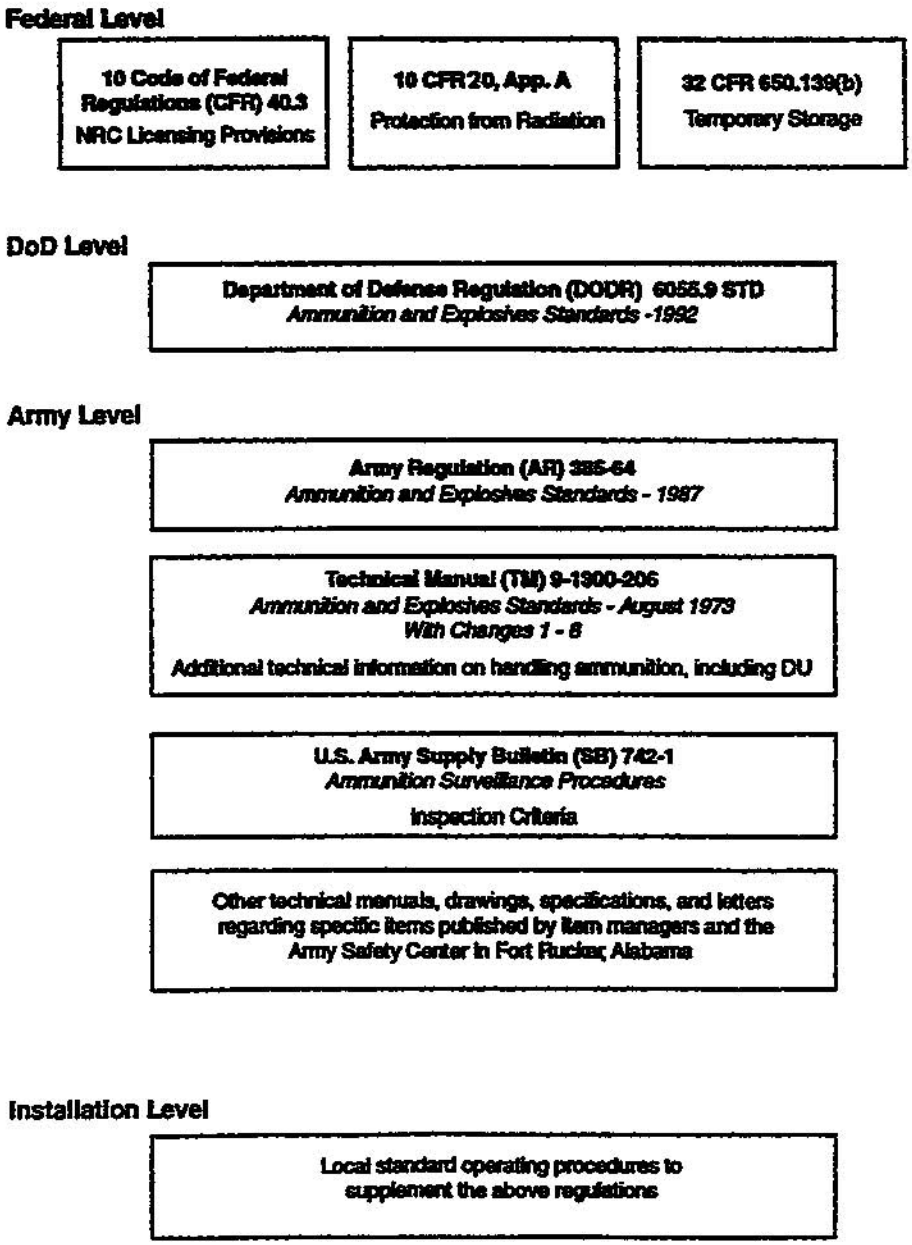
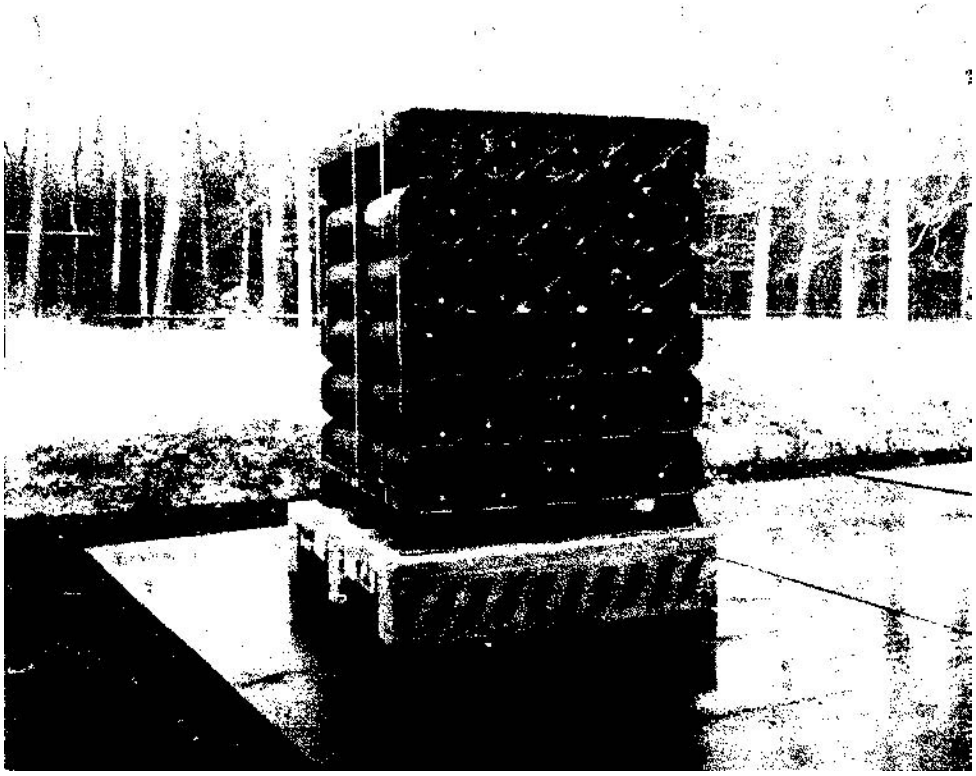


Figure 3-14. 30-Container Pallet of DU Ammunition Rounds



Storage capacity at depots, field ammunition supply points and basic load holding areas is restricted by NRC license possession limits and the amounts of explosives (TM 9-1300-206, 1973). The typical above-ground structure can hold 100,000 to 600,000 pounds of DU; however, some storage configurations may hold up to 1,700,000 pounds. The explosive hazards of the propellant exceed the DU radiation hazards and thus determine storage requirements. NRC regulations require the Army to identify DU storage areas as radioactive materials areas (10 CFR 20.1902(e)).

3.8 Ammunition Management

DODD 5160.65 assigned the mission of Single Manager for Conventional Ammunition (SMCA) to the Secretary of the Army. This made the Army responsible for depot and ammunition plant storage inventory of all

conventional ammunition (including DU) and explosives for all the military services. AMCCOM is the field operating agency responsible for executing this mission (DA, 1983). The Executive Director SMCA is located at AMC in Alexandria, Va.

The SMCA mission includes managing the production, storage and transportation of munitions. The mission excludes a few service-specific items, such as torpedoes, large rockets, smart bombs and missiles. The SMCA does not manage DU munitions inventories after they are issued for use overseas or to other services.

The Army National Inventory Control Point (NICP) manages the Army's worldwide stockpile of conventional ammunition and explosives. AMCCOM's Ammunition Directorate in Rock Island, Ill., serves as the NICP. It issues combat ammunition on demand. DU ammunition is used only in combat and is not issued for training.

3.9 Transportation

Two separate legal regimes—domestic and international—govern the transportation of low-level radioactive materials and waste. DOT and NRC regulations contain the domestic regime. Several United Nations (U.N.) conventions and agreements make up the international regime.

3.9.1 Domestic Transportation

DOT regulates the transportation of hazardous materials and hazardous waste in the U.S. (49 USC 1804 et seq). DOT regulations apply to DU both as a hazardous material and as a hazardous waste. NRC requires that shipments in government-owned aircraft conform to DOT regulations (10 CFR 71.5(b)). NRC or "agreement states" license the Army and its contractors to ship and receive DU. The shipper is responsible for ensuring that the

shipment complies with the requirements for shipping radioactive material and that the receiver is licensed to receive radioactive material.

To ship or transport DU munitions or armor, DA contractors must register with DOT. The Army, other federal agencies and state governments are exempt from this requirement (49 CFR 107.601, 606).

DOT regulates the labeling and packaging of radioactive material for shipment. Packages of radioactive material for shipment must be labeled according to 49 CFR. Packages that contain no radioactive material except DU are exempt from these DOT labeling requirements if the DU packaging meets alternative DOT standards. DOT also requires placarding of freight containers and transport vehicles containing hazardous materials (49 CFR 173.424, 172.500).

DOT requires employers to train workers who transport hazardous material. This training includes hazard awareness training, function-specific training, safety training, driver training, and EPA or Occupational Health and Safety Administration (OSHA) training that fulfills OSHA requirements (29 CFR 1910). Employers must maintain training records.

Four other regulations also govern interstate transport by the Army:

- Army Technical Manual (TM) 55-315, *Transportability Guidance for Safe Transport of Radioactive Materials.*

- Army Technical Bulletin (TB) 9–1300–278, *Guidelines for Safe Response to Handling, Storage, and Transportation Accidents Involving Army Tank Munitions or Armor Which Contain Depleted Uranium.*

- AR 55-355, *Defense Traffic Management Regulation.*
- 49 CFR 171–179.

Army installation and state requirements mostly mirror the requirements of DOT, DA, and 49 CFR 177–179. Tank armor is exempt from regulations that require radiation placards under 49 CFR 173.421 (B, C and D), 173.421-1 and 173.424. Ammunition is exempt from having a radiation placard under DOT Exemption E9649 but must have the explosive placard required by 49 CFR 172.522. Drivers must hold handling and firefighting instructions with shipping documents. The SMCA only allows DOT-approved carriers and military units to transport ammunition (Carpenter, 1993).

3.9.2 International Transportation

Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal (1989) governs the movement of hazardous waste across national borders. The U.S. Senate ratified this convention in August 1992. Implementing legislation was introduced in the House of Representatives on March 7, 1994. As of July 1994, the State Department was awaiting the outcome of the House action.

In 1990, the U.N. International Atomic Energy Agency (IAEA) resolved to strengthen international cooperation on nuclear and radiological protection. It recommended that the U.S. adopt the *Code of Practice on the International Transboundary Movement of Radioactive Waste* as policy (IAEA, 1990).

The code sets forth guidelines for ensuring the safe international movement of radioactive waste. It mandates that such movement should only occur with prior consent of the sending, receiving and transit nations. In addition, it requires that the owner should conduct all stages of

movement in a manner consistent with international safety standards. It also requires all nation states involved to have the administrative, technical and regulatory ability to fulfill their respective responsibilities for the movement. The code is advisory and does not affect existing or future arrangements among the nation states.

The code defines radioactive waste as "any material that contains or is contaminated with radionuclides at concentrations or radioactivity levels greater than the exempt quantities established by the competent authorities and for which no use is foreseen." DU may be covered by this definition. The U.S. has not yet adopted the code but has followed it.

According to customary international law, conventions such as the Basel Convention do not apply to vessels and aircraft with sovereign immunity (such as non-commercial craft on military or diplomatic missions). The Senate's ratification of the treaty and the House's implementing legislation both state this exemption to the convention.

The Army makes international shipments of DU systems under 49 CFR 173.421 or .424 (under DOT Exemptions E2136 or E9649) and the International Maritime Dangerous Goods (IMDG) codes for water shipments. Countries that do not accept DOT exceptions will accept U.N. Competent Authority Approvals signed by DOT.

3.10 Demilitarization

DODM 5160.65-M, *Single Manager For Conventional Ammunition*, covers the demilitarization of military items and implements conventional ammunition policies and procedures. Chapter 13, paragraph A, states, *"Demilitarization and disposal methods and procedures must be*

incorporated into the design and development of new or modified ammunition items. This technology must provide acceptable methods that comply with applicable environmental requirements." Subparagraph 1d. states, *"Included in the design of all new or modified conventional ammunition items is the requirement to develop safe and environmentally acceptable demilitarization procedures."*

In addition to the DoD requirements, U.S. Army Materiel Command Regulation (US AMCR) 75-2, *Demilitarization/Disposal Requirements Relating to the Design of New or Modification of Ammunition Items*, requires a system developer to publish a demilitarization disposal plan before the system goes into production. Additional AMC directives detail how to demilitarize materials in an environmentally acceptable way.

A Depot Maintenance Work Requirement (DMWR) contains specific demilitarization procedures. These documents provide the minimum technical information necessary to prepare standard operating procedures (SOP) for maintenance and demilitarization. They specify special safety, technical and production inspection requirements; tooling and equipment to be used; methods; procedures; materials; waste stream analyses; and reference documents. AMCCOM or its designee has prepared a DMWR for each DU munition, tank and mine containing DU. These are listed in Table 3-2.

The historical philosophy for demilitarizing tank ammunition was to separate the components (cartridge case, propellant, penetrator, etc.); to salvage them, where possible, for use in new cartridges; and to dispose of the remainder. The earliest DMWR for DU munitions used this philosophy with the exception that DU penetrators could be stored until they were needed or appropriately disposed as low-level waste (LLW).

The Army has written DMWRs for all DU tank munitions; however, it has not demonstrated the technologies with pilot plant investigations. These investigations are required to confirm that proposed technologies are adequate. The Army believed the concept for demilitarizing DU rounds was similar to that for tungsten rounds. Written procedures for DU demilitarization are similar to those for tungsten. The Army has not conducted proof of concept studies (to confirm the demilitarization technology) on a tank round since it validated the M735, a tungsten tank round fielded in the late 1970s.

Table 3-2. Depot Maintenance Work Requirements Documentation

REFERENCE ID	DMWR TITLE
AMCCOM, Undated	9-1315-C543-X20 Demilitarization of Cartridge, 105 mm: APFSDS-T, M900
AMCCOM, 1984a	9-1315-C524-X20 Demilitarization of Cartridge, 105 mm: APFSDS-T, M833
AMCCOM, 1984b	9-1320-D501-X20, Demilitarization of Improved Conventional Munition Projectile, 155 mm: HE, M692
AMCCOM, 1985a	9-1315-C523-X1 Demilitarization of Cartridge, 105 mm: APFSDS-T, M774
AMCCOM, 1985b	9-1320-D502-X20 Demilitarization of Improved Conventional Munition Projectile, 155 mm: HE, M731
AMCCOM, 1989a	9-1315-0000-P20 Preservation/ Packaging/ Packing of 120 mm Tank Ammunition (Extraction … from Damaged Containers)
AMCCOM, 1989b	9-1315-C786-F20 Renovation of Cartridge, 120 mm: APFSDS-T, M829
AMCCOM, 1989c	9-1315-0000-X21 Demilitarization of Cartridge 120 mm: APFSDS-T, M829
AMCCOM, 1992	9-1300-0001-D1 Demilitarization of Small Explosive Loaded Items, Change 1
AMCCOM, 1993	9-1305-A986-X20 Demilitarization of Cartridge 25 mm: APFSDS-T, M919

A new approach to the demilitarization of DU ammunition has been proposed. This plan links production of DU tank ammunition to the recovery of DU from demilitarized ammunition. The objective is to recycle DU penetrator material into new tank rounds. The Army hopes to create a closed loop system where it recycles DU and thus reduces both disposal costs and production costs for the manufacture of DU alloy from DOE stocks of DUF_6.

AMCCOM designated the IAAP as the site for future processing of DU tank munitions to the projectile or sub-projectile level (Kowalski et al., 1994). The AMC is contracting IAAP to build and install the necessary equipment. In addition, APG has disassembled 1,400 rounds of M774 tank ammunition to the component level and shipped it in equal amounts to each penetrator manufacturer. The contractors are evaluating the DU core chemistry for recycling. This evaluation will finalize the processes necessary to remelt and produce new DU penetrators. An AMC contractor will design, develop and install demilitarization equipment at IAAP during this evaluation. The Army plans to use about 1.5 million pounds of recycled DU for armor and penetrators in its purchase of M829A2 cartridges through 1997 (PM TMAS, 1993).

Propellant contaminated with DU may become a problem in the demilitarization operation. Batelle Pacific Northwest Laboratory (PNL) is investigating propellant disposal methods that are less likely to inject DU into the environment than open burning/detonation or incineration processes currently used for waste propellant destruction.

Demilitarizing DU tank munitions, like any manufacturing operation involving DU, is regulated for health, safety and environmental consequences. These regulations have been described in earlier sections of this report.

To demilitarize tanks with DU armor, TACOM will remove the DU from the armor package and release the decontaminated vehicle for standard Army salvage procedures. The plan is for DU armor to be recycled into new armor or projectiles. However, this process has not been implemented by TACOM, because no undamaged DU armored tanks have been demilitarized.

All Army ammunition and armor containing DU is within its minimum design life of 20 years. Therefore, no installation has conducted a mass disassembly of DU ammunition or armor. To avoid disassembly costs, the Army typically sells older ammunition to allied countries or gives it to them as military assistance. Historically, foreign sales reduced the need to demilitarize ammunition to damaged or otherwise unserviceable rounds. In 1994, approximately 150,000 rounds of unserviceable DU tank ammunition were inventoried for demilitarization.

The ADAM and the PDM contain DU [approximately 0.1 gram (g) by weight] as a curing agent for their epoxy/plastic casings. The ADAM is used as a submunition in the 155 mm howitzer (AMCCOM, 1984b). Tooele Army Depot recently completed a test using the Army Peculiar Equipment (APE) 1236 Deactivation Furnace, which is designed to demilitarize the ADAM. Preliminary analysis of the waste from this operation did not detect radiation levels above background. At the time of writing, final test reports were pending from Tooele Army Depot. AMCCOM will update DMWRs for the 155 mm projectile to reflect the findings of the Tooele Army Depot tests when the final report is released.

The GAU-8A/PGU-14 30 mm round, which the Army manufactures and demilitarizes for the Air Force, has an aluminum projectile with a fully encapsulated DU core. The Army DMWR specifies a piece of APE 2214 to demilitarize this ammunition.The APE 2214 breaks the projectile from the cartridge case, burns out the tracer, vacuums away the propellant and separates the projectile from the empty cartridge case.

AMCCOM used the APE 2214 (with some modifications) to develop the DMWR for the M919 25 mm cannon caliber ammunition in 1993. The scope of this DMWR is to separate the projectile from the cartridge case,

burn out the tracer, vacuum away the propellant, and separate the projectile from the empty cartridge case. The DMWR does not clearly define the final disposition of the DU projectiles accumulated by these operations.

3.11 Decontaminating / Decommissioning Army Installations

The Army has never decontaminated or decommissioned soft-target impact areas at its test centers, although it has disposed of some DU-contaminated soil as low-level waste. It does not expect to decontaminate its test centers, until it terminates the test missions or closes the installations. JPG discarded a small quantity of soil [less than 200 cubic feet (ft^3)] as LLW. The APG disposed of approximately 2,000 ft^3 of surface soil from the hard-target site on the Ford's Farm Range before building enclosed ranges in 1980 and 1989. Both sites sent their waste to the low-level waste disposal facility in South Carolina.

APG is decontaminating and decommissioning the Transuranic Range, which ARL-Aberdeen used for open-air testing and USACSTA used for a radioactive waste storage area.

YPG excavated a natural berm that impeded the flight of penetrators and stockpiled the soil near the line of fire at Gun Position 20 (Figure 3-15). YPG asked AMCCOM to dispose of the soil as radioactive waste in 1992, but AMCCOM delayed the project because it did not have funding. In an attempt to avoid unnecessary disposal costs, YPG then proposed to use the soil as a stopping media in future catch boxes. However, YPG has not received funding for a catch box at Gun Position 20, and moving the soil for use in the proposed catch box at Gun

Position 17A would be too expensive. In August 1994 this soil was excavated, transported, and disposed at the Envirocare facility in Utah.

Figure 3-15. Contaminated Soil Awaiting Disposal at YPG

Dense vegetation at APG and JPG makes it hard to recover penetrators manually and increases the potential for injury from UXO (Figure 3-16). In the desert (YPG), it is easier to see UXO and recover penetrators. All three test centers have recovered spent penetrators from impact areas and returned them to manufacturers for demilitarization and recycling. Manufacturers have historically used the DU from these recovered penetrators in commercial products. The Army does not currently recycle the DU recovered from ranges into new penetrators.

USACSTA has discontinued recovery efforts until its catch boxes are decommissioned. The Army does not plan to decommission the catch boxes until they contain 100,000 kg of DU, or airborne DU contamination becomes a hazard (as defined in 10 CFR 20, NRC, 1993b). JPG conducts recovery operations twice a year, in the fall and spring when vegetation is dormant. YPG conducts recovery operations monthly between firing programs. Each year the test centers calculate a mass balance of DU expended/recovered. The amount recovered averages between 21 percent (at JPG and APG) and 50 percent (at YPG) of the rounds fired.

Figure 3-16. DU Penetrator in Dense Vegetation at JPG

As a result of a 1989 General Accounting Office (GAO) report to Congress, *NRC's Decommissioning Procedures and Criteria Need to Be Strengthened*, NRC developed the Site Decommissioning Management Plan (SDMP) in 1990. This plan seeks to identify and resolve

issues associated with timely decontaminating and decommissioning of sites contaminated with low levels of radioactive material. The plan lists 46 sites with complex cleanup issues, excessive costs, or radiological hazards associated with decontamination. It also provides criteria for placing a site on the list or removing a site from the list. The list includes four Army installations contaminated with DU: APG, JPG, Watertown Arsenal and Lake City Army Ammunition Plant.

Test programs conducted by USACSTA at APG have contaminated approximately 1,200 acres of the test range with DU penetrators. Some groups have suggested that these penetrators could contaminate groundwater; however, evidence to date indicates that the soil characteristics at Aberdeen inhibit the formation of soluble DU compounds that could contaminate the groundwater.

Watertown Arsenal and Lake City Army Ammunition Plant are contaminated with DU from past operations. The SDMP list does not include JPG, YPG or ARL-Aberdeen. JPG has the same type of DU contamination as USACSTA at Aberdeen; thus, it meets the criteria for the SDMP list. DU penetrators are dispersed across 6,000 acres at YPG. ARL-Aberdeen has not decontaminated and decommissioned the Transuranic Range. (ARL's license is cited by the SDMP, but the activities described are USACSTA's.)

In April 1992, NRC developed a plan to accelerate remediation of the sites on the SDMP list (54 FR 13389). The Army has decommissioned Watertown Arsenal. Lake City Army Ammunition Plant has completed its site characterization and is developing its decommissioning plan. The NRC recently reviewed USACSTA's environmental sampling data at APG. These data showed that the groundwater is not contaminated and that the DU in the impact area does not present a health and safety hazard.

For these reasons, NRC should be removing Watertown Arsenal, Lake City Army Ammunition Plant and APG from the SDMP list.

3.12 Disposal

The Clean Air Act (CAA) classifies all substances containing radionuclides as hazardous substances (40 CFR 61; 42 USC 7412). Any substance classified as hazardous under CAA is also classified as hazardous under CERCLA (42 USC 9601). However, CERCLA excludes DU from its requirements if the release of DU into the environment occurs in compliance with a valid NRC permit, license, regulation or order (Stover, 1983). Furthermore, RCRA excludes DU in its definition of solid waste (Sharp, 1992). Disposal of DU is controlled by the Low-Level Radioactive Waste Policy Act (LLRWPA) and its amendments and by NRC regulations (10 CFR 61; 10 CFR 20). In the United States, the Army must manage expended DU ammunition and vehicles contaminated with DU according to LLRWPA. This act allows states to create regional compacts for low-level radioactive waste (LLRW) disposal. The Army must dispose of LLRW at either a federal disposal facility or a state compact facility. Two state compact disposal sites have been accepting LLRW from the federal government, but one of these (Snelling, S.C.) stopped accepting federal waste in July 1994; it is unclear how long the other (Richland, Wash.) will continue to accept government LLRW. Envirocare of Utah, a contractor-operated DOE facility, currently accepts DoD LLRW with some restrictions. The future of this disposal option also is uncertain.

The NRC regulations govern the transfer and disposal of low-level radioactive waste (10 CFR 30). They require that DU be transferred only to authorized

recipients, and they establish a tracking system and extensive record-keeping requirements for such transfers (10 CFR 20.2001, 2006). The NRC requires that radioactive waste only be disposed of at licensed land disposal facilities (10 CFR 20.2002). NRC further requires a waste generator to properly classify, describe, label and package radioactive wastes to be transferred to a disposal facility and to certify that they are in proper condition to be transported according to DOT regulations (10 CFR 20.2006). NRC regulations also provide that "land disposal facilities must be sited, designed, operated, closed, and controlled after closure so that reasonable assurance exists that exposures to humans are within the limits established in the performance objectives contained [within the regulations]" (10 CFR 61.40).

All applicants for NRC licenses must provide financial assurances that funding will be available to cleanup and decommission sites used for licensed activities (10 CFR 40.36; 10 CFR 30). NRC generally includes specific monitoring and/or cleanup conditions in the licenses it issues the Army. These conditions originally provided the Army with five disposal options, but now provide only two (46 FR 52061-63).

First, NRC allows the Army to bury low concentrations of DU with no restrictions on burial method. Under this option, the concentration of DU must meet EPA standards. In addition, the waste must not expose the public to more than 1 millirad per year (1 mrad per yr) of radiation to the lungs or 3 mrads per yr to the bone from inhalation and ingestion for any foreseeable use of the material or property. In addition, the concentrations must be low enough that no individual will receive an external dose in excess of 10 micro-roentgen (µR) per hour above background. These standards are compatible with guidelines recommended by EPA (42 FR 60956-60959; 46 FR 2556-2563).

Alternatively, NRC allows the Army to dispose of low concentrations of DU by burying them under prescribed conditions so that no subsequent land use restrictions and no continuing NRC licensing of the material are required. The concentration of DU must be low enough that no member of the public will receive more than 1 mrad per yr to the lungs, 3 mrads per yr to the bone, or 10 μR per hour above background if they avoid excavation in the burial grounds (46 FR 52061-63).

3.13 Army Radiation Protection Program

The Army has a peacetime radiation protection program for all phases of the DU life cycle to ensure that it does not expose Army personnel or the public to more radiation than allowed by NRC and EPA. The program has four cornerstones:

- NRC license requirements cover each phase of the DU life cycle. Therefore, the safety measures proposed for each phase are independently reviewed and, more importantly, independent inspections are conducted by NRC to ensure compliance with these safety measures. The Army maintains this oversight for both unclassified and classified portions of the program. The Army implements safety requirements equal to or more stringent than NRC license requirements in its overseas locations.

- The Army has developed regulations and established local programs (as required by NRC licenses) to ensure compliance with radiation safety regulations. These programs require the designation of a radiation protection officer (RPO) who is responsible for overseeing procedures involving DU, restricting access to areas containing DU munitions, and periodically testing for DU contamination on the exterior of munitions.

- Army regulations require personnel to comply with NRC contamination control and personnel monitoring procedures. NRC requirements vary from site to site, depending on specific missions. The site-specific procedures are reviewed by NRC, USACHPPM and the higher headquarters of each organization during inspections.

The radiation protection program requires program managers to perform health and safety evaluations and HHAs of all new systems containing DU. The Army Surgeon General must assess the health risks before DU munitions are fielded. This independent review, conducted by medical personnel not associated with the weapon's development, is a vital aspect of the Army's health and safety program. The primary focus of this review is the health risk, not the weapon's deployment.

3.14 Summary

Military, medical, space, aviation, heavy equipment and petroleum exploration applications all use DU. The Army uses it in kinetic energy penetrators, as a component in tank armor and as a catalyst for two land mine systems. One of these mines is used as a submunition for the 155 mm howitzer.

In acquiring new weapon systems, including DU systems, the Army follows DoD's Defense System Acquisition Process, which incorporates NEPA requirements. This process is implemented according to AR 70-1 and AR 200-2. To ensure system safety, the Army follows several regulations governing safety policies, procedures and testing: DoD Directive 5000.1, MIL-STD-882C, AR 385-16 and AR 40-10. Most control of DU production is handled by the NRC, which grants licenses to the Army and to Army contractors to possess and store

DU and to use it in munitions production. The AMC subordinates hold a total of 14 NRC licenses to develop, test and deploy munitions and armor containing DU.

The Army is responsible for all conventional ammunition (including DU metal and explosives) for all the military services. DOT and NRC regulations govern domestic transportation of DU; the IAEA and several U.N. conventions and agreements govern international transportation.

According to DODM 5160.65-M, the design of all new or modified conventional ammunition items must include the requirement to develop safe and environmentally acceptable demilitarization procedures. Specific demilitarization procedures for each type of DU munition, tank and mine are provided in DMWRs.

Although the Army has disposed of some DU-contaminated soil as low-level waste, it has never decontaminated or decommissioned soft-target impact areas at its test centers. The Army does not expect to decontaminate test centers until it terminates the test missions or closes the installations.

The Army has a radiation protection program for all phases of the DU life cycle to ensure that it does not expose its personnel or the public to more radiation than allowed by NRC and EPA.

4 COMBAT AND POST-COMBAT DU ISSUES

This chapter--

- Discusses the Army's use of DU-containing weapon systems during Operation Desert Shield/Desert Storm.

- Describes the effects of a DU-penetrator round striking a vehicle. This description is based on information obtained from 21 unfortunate friendly fire incidents.

- Discusses the number of rounds used in combat and practice.

- Describes how damaged and destroyed vehicles were handled, including the problems that personnel encountered in dealing with DU contamination.

4.1 Combat Experience

During Operation Desert Storm, DU armor on M1A1 Abrams tanks was not compromised by hostile fire. Iraqi rounds hit, but did not penetrate, the steel that covers the DU armor. The Army did, however, clearly demonstrate during Operation Desert Storm that DU kinetic energy rounds are more accurate and have a greater range than High Explosive Anti-Tank (HEAT) rounds (AAC, 1991). By using these DU weapon systems, the Army gave its soldiers better protection from enemy action and greater confidence in their ability to engage in and survive combat.

DU-penetrators have a "sharpening effect" upon impact that allows greater penetration through armor (Hartline, 1993; Danesi, 1990). Weapon testing shows that when a DU round penetrates an armored vehicle, it may pass completely through the vehicle (Figure 4-1) or ricochet around and fragment inside the vehicle. During Operation Desert Storm, an armor commander of the 1st Infantry Division said crews hit armored target vehicles at ranges in excess of 3,000 meters (1.8 miles). Tank commanders often fired more than one DU round at targets that were hit but did not explode. The commanders indicated that it was difficult to clearly determine that they had hit such distant targets (ACC, 1991).

Figure 4-1. DU Entry Holes in Bustle

Figure 4-2. Fire and Detonation Damage

When a kinetic energy round penetrates a vehicle, it contaminates the vehicle interior with dust and fragments. Metal fragments from the penetrator and the vehicle's hull can scatter inside the vehicle, killing and injuring personnel, destroying equipment, and causing secondary explosions and fires (Figure 4-2). As much as 70 percent of a DU penetrator can be aerosolized when it strikes a tank (Fliszar et al., 1989). Aerosols containing DU oxides may contaminate the area downwind. DU fragments may also contaminate the soil around the struck vehicle (Fliszar et al., 1989).

During Operation Desert Shield/Desert Storm, 29 U.S. vehicles were contaminated with DU on the battlefield, 21 of these were unfortunate friendly fire incidents involving DU munitions. DU rounds penetrated six crewed

Abrams tanks. One Abrams tank crew member was killed, seven were wounded and the rest were unharmed (DoD, 1992; OASD, 1991). DU penetrators also hit 15 Bradley Fighting Vehicles. Twelve Bradley crew members were killed, 43 were wounded and the others were unharmed. In addition to friendly fire, the Army used multiple DU rounds to destroy three unoccupied Abrams tanks to prevent enemy capture. Five other Abrams tanks were contaminated during on-board fires involving their own DU rounds.

The Army and the Marine Corps used more than 14,000 large caliber DU rounds during Operation Desert Shield/Desert Storm (Hull, 1993). During Operation Desert Shield, tank crews fired many DU rounds for practice to verify the correction factor for their tanks' fire control computers. Most of these rounds were fired into large sand berms that backed the target arrays at practice ranges in Saudi Arabia (DoD, 1992). If one assumes that each of the more than 1,800 tanks involved fired an average of four practice rounds, then more than half the DU rounds expended during Operation Desert Shield/Desert Storm were concentrated on practice ranges in Saudi Arabia.

The Army and Marine Corps tanks fired approximately 4,000 DU rounds in combat.[1] Most were fired in the desert, many miles from the nearest village, on battlefields several hundred square miles in size. Although these DU penetrators may be clustered where U.S. tanks fired on Iraqi targets, most are probably impossible to locate.

Army recovery crews found some DU penetrators on the ground, picked them up and turned them in for disposal. For example, one U.S. tank was hit by three DU penetrators and set ablaze. Its DU ammunition "cooked off," expelling penetrator sub-assemblies around the burned out hull. Recovery crews collected these sub-assemblies and

turned them in, even though there was no policy to do so. The DCF at Snelling, S.C. reported that it received 503 DU penetrators after Operation Desert Storm.

Most DU penetrators fired in combat will be in one of three places:

- *In or near target vehicles:* Eighty to ninety percent of tank rounds fired will hit the target and remain in or near it.
- *On the soil surface:* Projectiles that miss the target will often ricochet, skipping across the ground. These projectiles usually land within a mile or two of the target.
- *Buried in the soil:* Some projectiles will penetrate the ground. The percentage of buried rounds depends on engagement angles and ranges, soil types and terrain.

4.2 Retrieval After Combat

After the Army has fought a battle and the combat forces have moved on, medical, graves registration, and equipment recovery personnel remove the wounded and dead and recover U.S. equipment. Damaged U.S. equipment is repaired on site, stripped and/or removed to rear maintenance collection points. Equipment recovery personnel usually leave enemy equipment in place. Equipment contaminated with DU oxides can become a source of contamination when the oxides are resuspended, blown, washed, or otherwise dislodged during transit.

Units are responsible for recovering or arranging for recovery of their vehicles from the battlefield to battalion, brigade, or division maintenance collection points. Additional units remove vehicles from division collection maintenance points to support command maintenance collection points for further repair or disposition. Thirteen Abrams and 15 Bradleys, contaminated with DU during Operation Desert Storm, were returned to the 144th Service

and Supply Company, Army National Guard (ARNG) at King Khalid Military City, Saudi Arabia. One additional DU-contaminated tank, damaged by a fire in December 1990, was sent directly to DCF in January 1991.

The 144th Service and Supply Company was responsible for establishing a central receiving and storage point for all damaged and destroyed combat vehicles (Figure 4-3). It assessed battle damage to vehicles and prepared them for shipment back to the U.S. Before the 144th went to the Persian Gulf, most of its experience with combat vehicles involved M109 and M110 self-propelled howitzers, not Abrams tanks or Bradley Fighting Vehicles. Furthermore, the 144th personnel were not familiar with current procedures for handling DU tank armor and ammunition to minimize contamination. Two Army publications could have provided guidance to the unit on appropriate procedures: TB 9-1300-278, *Guidelines for Safe Response to Handling, Storage and Transportation Accidents Involving Army Tank Munitions or Armor Which Contain Depleted Uranium* and TM 9-2350-264-10-2, *Operator's Manual*: *Unusual Conditions, Trouble Shooting and Maintenance, Tank, Combat, Full-Tracked: 120 mm Gun, M1A1 (2350-01-087-1095) General Abrams.* The 144th did not have TB 9-1300-278 because its original mission did not involve tanks. It did not have TM 9-2350-264-10-2 because of a distribution delay.

The 144th placed DU-contaminated vehicles in a recovery yard without controlled access. Several vehicles were covered with tarps, camouflage nets or shelter halves (AMCCOM, undated b). Company personnel told the General Accounting Office (GAO) that 20 to 25 soldiers from the company worked on Bradleys and Abrams vehicles without knowing the vehicles had DU contamination or potential radiation hazards. The soldiers said they did not wear protective gear until approximately 3 weeks after they

had begun work, when the AMCCOM radiological team arrived and advised them of radiological hazards (GAO, 1993).

The AMCCOM Radiological Waste Disposal Division handles low-level radioactive waste for DoD. In March 1991, the AMCCOM radiological team went to Saudi Arabia to oversee collection and preparation of DU-contaminated vehicles for shipment back to the U.S. Upon arrival, the team found that the contaminated vehicles were scattered throughout the maintenance collection point and that no measures had been established to limit personnel exposure. The team separated the contaminated vehicles, established a security perimeter to limit access, and instructed 144th personnel who staffed the maintenance collection point in precautions for handling DU (AMCCOM, undated b). Access to the DU-contaminated vehicles was limited to specific members of the 144th, the AMCCOM radiological team, the battle damage assessment team, selected explosive ordnance disposal team members and the PM survivability team.

Figure 4-3. 144th Service and Supply Company's Central Receiving and Storage Point

The AMCCOM radiological team concluded that the vehicle contamination was low enough that it required relatively few anti-contamination procedures. Personnel allowed access to the contaminated vehicles had to wear dust masks and thin surgical gloves, had to wash their hands and faces before eating, and had to wash their clothes at the end of the day. Personnel who entered or worked on the contaminated vehicles were cleared before they left the secured DU compound. Clearance consisted of a radiological survey of the entire body with portable radiation detectors, followed by decontamination, if required (AMCCOM, undated b).

4.3 Battlefield Cleanup

After Operation Desert Shield/Desert Storm, Kuwait divided the country into seven sectors for battlefield cleanup. It awarded contracts to private organizations from the U.S., France, United Kingdom, Bangladesh, Pakistan, Turkey, and Egypt. Historically, the host country is responsible for managing the consequences of a battle.

Ultimate disposition of enemy equipment captured during Operation Desert Storm varied. Immediately after combat, DoD, DA and the intelligence community removed captured equipment of interest (Figure 4-4). Some units selected captured equipment to return to the U.S. as unit history items. Most captured items were either turned in to designated collection points or left on the battlefield for subsequent disposition. The AMCCOM radiological team conducted radiological surveys and chemical hazard assessments to help DA and U.S. Customs identify hazardous materials on or in equipment that Army units selected as historical items.

Three DU-contaminated Iraqi vehicles were rejected for shipment to the U.S. in this screening. The screening also considered the possibility that vehicles may have contained

hazardous materials such as polychlorinated biphenyls (PCBs) and asbestos. In addition, it showed that instrument dials on some Iraqi equipment manufactured by Warsaw Pact nations were painted with radium and promethium (^{147}Pm). According to the U.S. Army Foreign Science and Technology Center (FSTC), some sighting systems, such as those on the ZSU 23-4 anti-aircraft gun, contained tritium or radium to provide illumination, and some chemical detection instruments contained small amounts of plutonium. According to FSTC, captured equipment now stored at equipment collection points in Kuwait probably contains these and other hazardous materials (FSTC, 1993). It does not appear that Kuwait has addressed the long-term management of hazardous and radioactive materials in captured vehicles.

Figure 4-4. Iraqi Armored Car

Unless they received a special request, installation radiation protection officers (RPOs) would not necessarily survey equipment brought back as historical items for DU or other contamination. USACHPPM would not necessarily survey these items unless it received a special request or unless an inspection was performed as an adjunct to its triennial inspection of licensed materials (Edge, 1994). Foreign equipment released through FSTC, on the other hand, is routinely subjected to a formal hazardous substance survey. Hazardous items identified during this process are either removed, documented, and/or controlled under the general NRC license held by the U.S. Army Intelligence Agency (Cardenuto, 1993c). Therefore, historical items in unit and installation museums that were not obtained through FSTC may contain hazardous materials (Jensen, 1994).

During Operation Desert Shield/Desert Storm, the Army did not have an effective strategy for removing DU from ground combat vehicles so it could quickly repair or scrap them. Before Operation Desert Shield, only three tank fires had occurred involving DU ammunition since the Army first fielded it in 1980. In 1983, an M60A1 tank was damaged by fire and contaminated by its DU ammunition. The tank was decontaminated and, because of extensive fire damage, was then sold as scrap in the U.S. In 1988, two fire-damaged M60A3 tanks were shipped from Europe to the U.S., where they were buried intact at the low-level radioactive waste site in Snelling, S.C. (GAO, 1993).

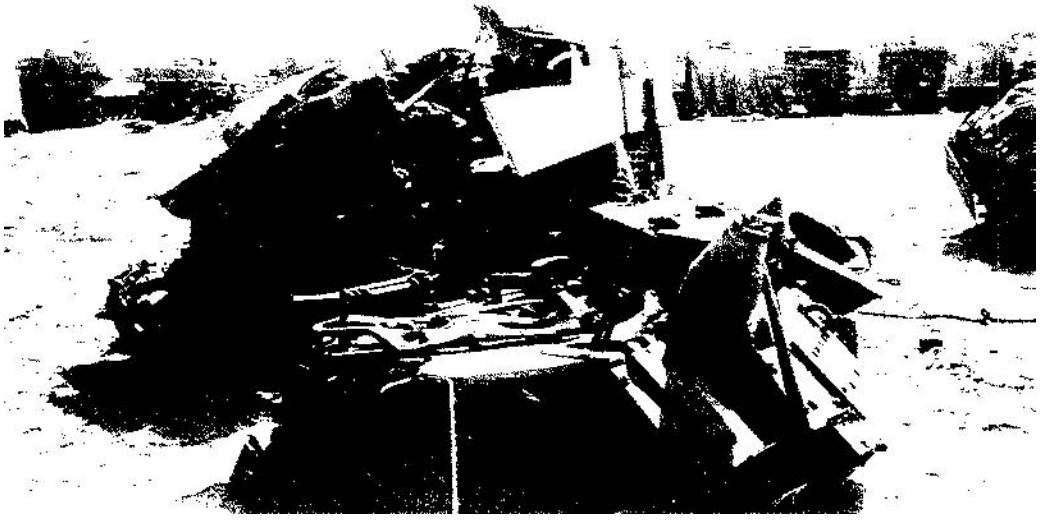
The AMCCOM radiological team developed an *ad hoc* protocol to manage DU-contaminated vehicles after Operation Desert Storm.[2] The prewar strategy of burying war-damaged vehicles intact at a U.S. disposal site was inappropriate because of the number of contaminated vehicles (GAO, 1993). Radioactive waste disposal is expensive and many lightly damaged vehicles can be repaired once

DU-contaminated portions are removed. Consequently, AMCCOM adopted the following strategy for dealing with DU-contaminated vehicles from the war:

- Decontaminating the exterior of the vehicles.
- Shipping the vehicles to DCF, Snelling, S.C. where the Army's contractor for consolidating low-level radioactive waste (Chem-Nuclear Systems, Inc.) could remove contaminated portions and bury them at the low-level radioactive waste disposal site in Barnwell, S.C.
- Repairing decontaminated vehicles, when possible, at an appropriate facility. If a vehicle was irreparable, removing reparable and classified components and selling the rest as scrap.

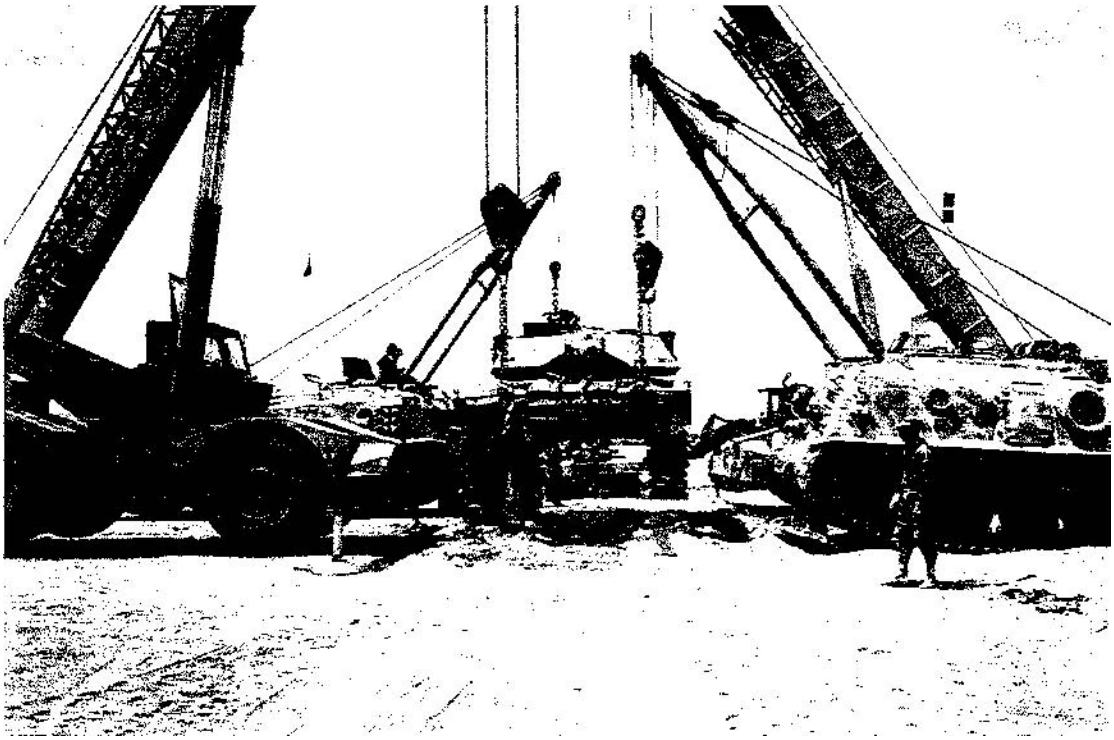
As previously stated, during Operation Desert Shield/Desert Storm, 29 U.S. Army combat vehicles—15 Bradley Fighting Vehicles and 14 Abrams tanks—were contaminated after they were hit by DU rounds from Abrams tanks or after accidental on-board fires ignited stored DU ammunition. The Army buried six destroyed Bradleys (Figure 4-5) at King Khalid Military City. These

Figure 4-5. Destroyed Bradley Fighting Vehicle



vehicles were not returned to the U.S., because the certifying officer was unable to declare that the wreckage was free of unexploded ordnance. Burial appeared the safest and most cost-effective solution. The remaining nine Bradleys and the 14 Abrams were wrapped in tarps to reduce dispersal of DU contamination during shipment. These vehicles were shipped to DCF (Figure 4-6) for decontamination, or repair (AMCCOM, undated b; GAO, 1993).

Figure 4-6. Packaging of MI Abrams for Shipping Back to DCF



Decontamination of these 23 vehicles was delayed, because DCF was not large enough to handle both the Desert Storm DU-contaminated vehicles and its regular workload of low-level radioactive waste. A new facility was built to decontaminate the heavy tanks and fighting vehicles. In June 1992, the Army completed construction of a new $4 million building at DCF to accommodate the larger, heavier vehicles. After the building was approved by a

Safety Review Board audit mandated by South Carolina, Chem-Nuclear Systems began work there in October 1992.

As of October 1, 1993, DCF had decontaminated eight of the nine Bradleys and four of the 14 Abrams tanks. Of the four decontaminated tanks, two were sent and a third will be sent to Anniston Army Depot, Ala., for repair before being returned to service. The fourth tank had been involved in an accidental fire. DCF buried the contaminated interior and cut up and sold the tank body as scrap, minus reparable and classified components. DCF sent the eight decontaminated Bradleys to the Red River Army Depot in Texas for reuse. Once the remaining Bradley has been decontaminated, it also will go to Red River.

4.4 Summary

The use of DU appears to have given soldiers in Operation Desert Storm more effective weapons, better protection from enemy action, and greater confidence. However, 21 unfortunate friendly fire incidents involving DU munitions killed a total of 13 soldiers and wounded 50.

Of the approximately 4,000 DU rounds the Army and the Marine Corps fired in combat, most remain in isolated areas of the desert.

Twenty-nine U.S. combat vehicles were contaminated with DU. Equipment contaminated with DU oxides and particles can contaminate people and other equipment when particulates are resuspended, blown, washed or dislodged. Twenty to 25 members of the 144th Service and Supply Company, Army National Guard, worked without protective gear on contaminated, damaged vehicles for three weeks, until the AMCCOM radiological team arrived and advised them of radiological hazards.

The Army buried six destroyed vehicles in Saudi Arabia. It shipped the remaining 23 vehicles, after mitigating the potential for dispersal of DU contamination, to DCF for decontamination, salvage, or repair.

The AMCCOM radiological team and the U.S. Army FSTC screened many items returned to the U.S. as historical items in unit and installation museums. Items not obtained through FSTC may contain hazardous materials.

Endnotes

1. A large number of DU rounds used in Operation Desert Shield/Desert Storm were destroyed during a fire at an ammunition depot.

2. The AMCCOM Safety Office forwarded a draft of the Retrograde Plan for Damaged Radioactive Materials or Materials Contaminated with Radioactive Materials to AMC on April 16, 1993. This plan is written for the combat commander and addresses all levels that may be involved with DU-contaminated equipment or personnel.

Part II: RESPONSE TO CONGRESSIONAL TASKINGS

The Senate Appropriations Committee tasked AEPI through the Office of the Assistant Secretary of the Army for Installations, Logistics and Environment to conduct a study to determine four things:

- The health and environmental consequences of using DU on the battlefield.

- The availability of remediation technologies for cleaning up DU contamination.

- Ways to reduce the toxicity of DU.

- Ways to best protect the environment from the long-term consequences of DU use.

Part II presents and discusses the issues identified by AEPI as they relate to these four tasks and the broader issue of DU management by the Army.

Chapter 5 overviews previous major studies that have considered the health and environmental consequences of Du use by the Army. Chapter 6 presents information on the health risks associated with the Army's use of DU and discusses the possibility of reducing DU's toxicity. Chapter 7 addresses environmental risks, reviews available remediation technologies and provides suggestions for protecting the environment from long-term consequences of DU use. Chapter 8 offers findings and conclusions derived from the study.

5 PREVIOUS DU STUDIES

The primary health and environmental risks of using DU arise from the internalization of metal fragments and oxides generated by penetrator impacts, from fires involving DU munitions, and from oxidation of DU penetrators in the natural environment. To quantify these risks, one must know the quantity and the physical and chemical properties of the oxides generated and how these change with time, and use the appropriate environmental and health effects models to estimate the potential intake through each pathway.

Previous studies of the health and environmental consequences of the use of DU have indicated that the Army needs to conduct several additional investigations to more fully understand its consequences. The Army can improve the experimental procedures it uses in these investigations.

5.1 Findings of Previous Studies

Before the Army used DU in penetrators, the Office of the Director Defense Research and Engineering (ODDR&E) tasked the JTCG/ME to perform an initial assessment to "... evaluate the medical and environmental implications of the use of depleted uranium and alternatives in a variety of conventional munitions. ..." The JTCG/ME was also tasked with analyzing each phase of the DU life cycle, including combat operations, and recommending research required to confirm any of its conclusions (JTCG/ME, 1974).

The JTCG/ME concluded that "Overall, implementation of the proposed action [the development and use of DU penetrators] is expected to have no significant medical and environmental impact. Depending upon conditions locally, significant impact can occur in the event of uncontrolled release of DU." Specifically, it concluded that implementing the regulatory requirements of the Atomic Energy Commission (now NRC), DOT and OSHA would effectively control the internal and external hazards of DU for all peacetime activities (mining, manufacture, transportation, storage and RDT&E). The JTCG/ME further concluded that fires or accidents involving DU munitions and the use of DU munitions in combat could result in locally significant internalization (inhalation, ingestion and embedded fragments) (JTCG/ME, 1974).

The primary shortcomings of the JTCG/ME analysis were the following:

- The lack of data on the amount and characteristics of airborne DU that combat and fires could generate.

- The lack of definitive assessments of the environmental behavior of DU.

The JTCG/ME recognized these information gaps and specifically recommended that the Army initiate research to characterize the products from target impact to determine environmental corrosion rates, to assess the impact of alloying on solubility, and to determine the long-term health effects of embedded DU.

M.E. Danesi, the U.S. Army Pierre Committee, and the NMAB of the National Academy of Science's National Research Council each conducted similar evaluations (Danesi, 1990; Pierre Committee, 1979; NMAB, 1979). Each

of these reviews concurred with the overall conclusions of the JTCG/ME on the health effects of military use of DU.

5.2 Depleted Uranium Characterization

The Army has conducted many tests to determine the characteristics of particles produced by hard and soft target impacts and by fires involving DU munitions and armor. Unfortunately, data that the AEPI reviewed did not contain the attributes required to estimate inhalation potential or environmental transport. AEPI is conducting an exhaustive review of existing particle data to better define data gaps.

The data from each burn test were consistent and reproducible. However, the technology for assessing health and environmental risk has advanced greatly in recent years. Therefore, these data are not sufficient to support the data needs of the new health and environmental risk assessment techniques. For example, tests designed to characterize the aerosols created when a DU penetrator strikes a combat target found significant differences in particle characteristics of the different types of rounds and different types of targets. Investigators made no attempt to critically evaluate the reasons for these differences. They assumed that differences in munitions and targets or errors in experimental design caused the inconsistent results. Unless researchers clearly understand these data, they are of limited use for evaluating health and environmental consequences.

Thus, after AEPI's critical review of the available particle characteristic data, studies must be designed to generate requisite data. These data must be suitable for use in calculating environmental and health risks from aerosols generated in fires and hard- and soft-target impacts, and they should identify and characterize the oxides formed when penetrators are exposed to the environment. At a

minimum, these data would include chemical species, mass-mean size, surface-mean size, size distribution, specific gravity by species and particle shape factors.

5.3 Experimental Procedures

AMC has conducted many tests on the potential hazards of DU munitions and armor. However, these data have often been insufficient for calculating health and environmental risks. Individual PMs decide when to investigate potential hazards, and researchers conduct experimental procedures and data analyses without external peer review to validate the quality or completeness of their work. Thus, the Army does not appear to closely coordinate the planning and performance of experiments for DU health and environmental assessments.

Many weapons performance experiments have also produced data for the Army to use in evaluating the potential health hazards of battlefield use of DU munitions and armor. Three investigation topics are particularly significant:

- Radiological doses received by crews in tanks loaded with DU munitions (ARDEC, 1990; Parkhurst et al., 1991).

- DU aerosols generated by DU munitions (40 CFR 61; Jette et al., 1990).

- DU aerosols resulting from the impact of various types of munitions on DU-armored tanks (Fliszar et al., 1989).

However, it appears that these tests were done to evaluate the effects of DU in particular conditions, not to test theories that might be used to develop a predictive model to

estimate DU-aerosol generation and transport under battlefield conditions. If researchers could develop such a model, it would reduce the need to retest each time munitions, target characteristics or environmental conditions change.

Army studies need to review and assess similar previous investigations. For example, AEPI researchers identified four studies of DU aerosolization during munitions and armor testing that used similar experimental methods (Fliszar et al., 1989; GenCorp Aerojet, 1993; Gray, 1978; Haggard et al., 1986). Although the studies were otherwise excellent, none of the more recent studies compared their results with those from earlier studies. This comparison is necessary to check the validity of results and to force researchers to critically review differences and develop explanations for them. This step is essential in developing a fundamental understanding of particle characteristics and in developing predictive models.

The DU-particle resuspension has become a major concern since Operation Desert Storm. Particulate resuspension data were derived from air samples taken on single vehicle impact tests or fires. The resuspension potential for the test cases is not comparable with that on the battlefield. During a battle, multiple vehicles can provide a source for DU particles (fires and impacts) or can mechanically resuspend DU by their movements. Thus, without a firm grounding in aerosol mechanics theory, test results are only valid for the testing conditions and cannot be generalized over diverse environmental conditions (soil composition, vegetation, weather, etc.). The Army needs general models that are sufficiently robust to provide defensible estimates of the aerosol and particulate concentrations of DU on the battlefield.

Erikson's work is a good example of how researchers should mix theory and experimentation (Erikson et al., 1990a). Erikson studied the mobility of DU at two U.S. test sites. The study had a firm theoretical basis that guided measurements and served as a bench mark to test the validity of the data. While the objective of the experiment was limited to two specific test sites, the methodology Erikson used makes the data more broadly applicable. These data can be used as a starting point for estimating the environmental fate and effect of expended DU penetrators under other environmental conditions. The only major shortcoming of the Erikson study was that it did not receive independent peer review.

The system developer PM should require peer review of all health and environmental aspects of proposals, data and reports concerned with DU contained in the weapon system. Peer review of proposals will ensure that the experimental approaches are sound and that the work is likely to yield new, valuable information. It will also ensure that the personnel performing experiments have the necessary expertise. Peer review of final reports will ensure that researchers conducted experiments correctly and drew scientifically defensible conclusions. Reports should be reviewed inside and outside DoD to increase the number of expert reviewers and to enhance the credibility of reports. Independent peer review is crucial because too often studies are performed by or for an organization that has a vested interest in the results.

For example, based partly on Cole's experimentation and analysis, Danesi concluded that soldiers can safely take refuge in a DU-contaminated vehicle (Cole, 1989; Danesi, 1990). Cole works for a DU munitions manufacturer, and Danesi cited an internal report, sponsored by the manufacturer, that did not undergo an independent review.

In spite of the high quality of Cole's report, its conclusions are less credible because they lack rigorous independent confirmation.

The Army has and is conducting many tests to assess the environmental and health hazards associated with all phases of DU use. It could improve the usefulness of the data already gathered and the quality, dependability and cost-effectiveness of future testing by taking four actions:

- Critically reviewing all environmental and health hazard data obtained to date to ensure that it is consistent and scientifically defensible, to identify critical data gaps, and to recommend methods to fill these gaps.

- Emphasizing the development of theoretical models and their use in planning experimental research to maximize the cost effectiveness of experiments.

- Establishing a mechanism for scientific peer review of proposed experiments and their results.

- Identifying a focal point and repository for all information on the health and environmental effects of DU. This organization could consolidate available environmental data and thereby reduce duplication and ineffective experimentation.

5.4 Summary

Four previous studies have examined the health and environmental effects of the use of DU in conventional weapons: a 1974 study by the JTCG/ME, a 1979 study by the U.S. Army Pierre Committee, a 1979 study by NMAB of the National Academy of Science's National Research Council, and a 1990 study by Danesi.

The JTCG/ME study concluded that the overall use of DU penetrators would have no significant medical or environmental impact but that, depending on local conditions, an uncontrolled release of DU could have a significant impact. Further, it concluded that implementing regulatory requirements of NRC, DOT and OSHA would effectively control DU hazards during peacetime. It also concluded that fires or accidents involving DU munitions and the use of DU munitions during combat could cause locally significant internalization. The three later studies concurred with these conclusions.

The Army has conducted many tests to determine the characteristics of particles produced by hard- and soft-target impact and by fires involving DU munitions and armor. These tests have not produced all the appropriate data required to calculate scientifically defensible health and environmental risks. Many of these data were collected before modern risk assessment technologies were developed. The Army needs to establish a health and environmental data protocol to ensure that testing produces data that are appropriate for developing health and environmental policies.

6 HEALTH ISSUES ASSOCIATED WITH U.S. ARMY USE OF DU

This chapter discusses the state of knowledge concerning DU's chemical and radiological toxicity to humans. Many scientists argue that chemical toxicity from internalizing DU particles is many times greater than the carcinogenic toxic effects that radiation exposure can cause. Others argue that the long-term carcinogenic toxic effects, due to internal radiation exposure from internalized DU, are the most critical DU-health issue. The Army is concerned about the health effects of both types of toxicity. We seek to describe the health concerns associated with both phenomena in this chapter. This chapter considers the following key areas:

- Human health effects from incidental DU contact and the more medically significant issues of ingestion, inhalation, wound contamination, and injection (embedded fragments).

- Current Army medical protocols for DU-wound management.

- Current Army DU-awareness training and opportunities to standardize training for all personnel regarding DU's hazards.

- Opportunities to standardize labeling of materials containing DU.

6.1 Radiological and Chemical Toxicity of Depleted Uranium

Before using DU the Army evaluated the health risks of soldiers' external exposure to DU munitions and armor in training, operations and combat. The risk to soldiers handling DU was found to be insignificant and within applicable standards (Danesi, 1990). Current operational procedures ensure the health and safety of personnel by minimizing external exposure to intact DU armor and DU munitions during combat and training. (Some vehicles with DU armor are used in training; DU ammunition is not used in training). Current data reveal that DU presents a medical concern only if it enters the body.

The health risk of exposure to low-level radiation is a complex issue. Many in the scientific community disagree over how to estimate the risk. Some issues associated with the radiological and chemical toxicity of DU used in Army weapon systems are not fully resolved (Daxon and Musk, 1992).

Many elements and chemical compounds can produce adverse health effects under certain conditions. Heavy metals are usually toxic. Some are in common use, such as chrome used for plating or cadmium in rechargeable flashlight batteries. DU is a heavy metal with the toxicological risks shared by other heavy metals such as lead, cadmium, nickel, cobalt and tungsten. While health risks from DU may be affected by individual susceptibility to uranium's toxic effects and to concurrent exposure to other toxicants, the health risks from DU are largely dependent on three factors (ICRP, 1979):

- The amount present.
- The chemical and physical form of the DU.
- The duration and mechanism of exposure.

Danesi (1990) discusses the health risks of exposure to DU munitions during each phase of their life cycles.

If DU enters the body, it has the potential to generate significant medical consequences. The risks associated with DU in the body are both chemical and radiological. Small particles generated in fires or during the impact of penetrators on armor may enter the body by inhalation, ingestion (for example, by ingesting contaminated food or water), and by deposition in open wounds. During combat, soldiers may be wounded by metal fragments that contain DU. The solubility of the DU-containing material in bodily fluids is the primary determinate of the rate at which the uranium moves from the site of internalization [lung for inhalation, gastrointestinal (GI) tract for ingestion, or the injury site for wound contamination and injection], into the blood stream and then to the organs. In most instances solubility also determines how quickly the body eliminates uranium in urine or feces.

Experimental data from weapon system RDT&E and from field experience during Operation Desert Storm indicate that the potential for DU internal exposure during combat is directly related to the location of the soldiers exposed.

Soldiers in or near vehicles struck by DU munitions are most likely to receive internal DU exposures. The Operation Desert Storm fratricide incidents showed that soldiers in armored vehicles can survive DU penetrations and can have DU-fragment wounds and DU-wound contamination.

Recovery and maintenance soldiers working in and around DU contaminated vehicles can inhale or ingest resuspended DU particles. Monitoring of research workers, maintenance, and recovery soldiers has not evidenced internal exposures; however, the Army should conduct

further experiments to better define the risks from resuspended particles. These experiments would provide sufficient information to develop maintenance protocols that include the use of personal protective equipment by workers, if appropriate. Soldiers may be incidentally exposed to DU from dust and smoke on the battlefield. The Army Surgeon General has determined that it is unlikely that these soldiers will receive a significant internal DU exposure. Medical follow-up is not warranted for soldiers who experience incidental exposure from dust or smoke.

6.1.1 Health Risks from Radiation

This section provides information on the background exposure from natural radiation received by all inhabitants on earth. In the U.S., radiation from natural background sources exposes everyone to about 300 millirem per year (mrem/yr) [National Council on Radiation Protection and Measurments (NCRP), 1987b]. People who live at high altitudes and in areas rich in radioactive minerals receive several times the background dose of those who live in most coastal plains. However, regardless of location, we are exposed to naturally occurring radiation and radioactive elements (some of which are metabolized by our bodies). The NRC's standard for public exposure to man-made sources of radiation is 100 mrem/yr above background (10 CFR 20.1301). Distinguishing between natural background and exposure above background is sometimes confusing. Radiation levels are reported in rads, rems and roentgens. The prefix "m" ("milli"), as in mrem, means 0.001 rem.

The scientific community agrees that the models for estimating cancer and genetic anomalies caused by low-level radiation exposure overstate the actual hazards [Biological Effects of Ionizing Radiaton (BEIR), 1980, 1989, 1990; United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), 1986, 1988, 1993, 1994]. Risk estimates used for low-dose exposure are extracted from

high-dose/high-dose rate data. Risks from acute radiation exposure (greater than 100 rem) are relatively well-established. Reports by ICRP and the National Research Council's Committee on the Biological Effects of Ionizing Radiation (BEIR, 1980, 1989, 1990) contain excellent summaries of the literature concerning the human health effects of radiation exposure. Because extracting the risk estimates at low doses is a theoretical and not an experimental process, experts disagree somewhat as to which models best describe different types of exposures (BEIR, 1980, 1989, 1990; UNSCEAR, 1986, 1988, 1993, 1994).

Several studies (summarized in BEIR, 1980, 1989, 1990; UNSCEAR, 1988, 1993, 1994) were conducted on populations receiving low– dose/low–dose rate radiations from occupational exposures, exposures to nuclear weapon's fallout, medical sources of ionizing radiation, and living in areas with high natural background radiation. In the assessment of the results of these studies, the BEIR V (BEIR, 1990) committee concluded that there was no detectable increase in cancer rates in these populations. The committee did not conclude that there were no radiation effects; it did conclude that these results were consistent with their estimates of risk and indicated that risk estimates based upon high–dose/high–dose rate data do not underestimate the risk of low–dose/low–dose rate exposure.

All health and safety protection standards are set at levels below the risk of adverse health effects that is considered acceptable (ICRP, 1977; NCRP, 1993b). The concept of acceptable risk is relatively straightforward for exposures that have a threshold level below which adverse health effects do not occur. These types of effects include chemical toxicity and some radiation effects such, as radiation burns or sickness. The severity of the injury increases as the exposure is increased.

Determining risks for radiation–induced cancer and genetic effects is complex. There is no threshold dose. There is a relationship between increased incidence of disease and radiation exposure. Thus, unlike "threshold–effects," there is always risk associated with exposure for non–threshold radiation effects. The radiation protection standards that address "non–threshold effects" represent a risk level that is considered acceptable through national and international agreements. As such, these standards define the accepted risk level posed by non–threshold effects.

When compared to other common radioactive isotopes, health risks from internalized DU are small. Table 6–1 compares the relative radiation dose a person would receive, per unit mass internalized, for various common radionuclides. The radiation dose received from each of the following would be vastly different if a person were to internalize them: DU, uranium in the natural isotopic ratio, ^{226}Ra, or americium-241 (^{241}Am). Specifically, if the radiation dose from DU is taken as the base unit (1 unit), the dose from the same amount of natural isotopic uranium would be 1.7 units; the dose from ^{226}Ra would be 200,000 units; and the dose from ^{241}Am would be 30,000,000 units. Promethium-147 (^{147}Pm) and ^{226}Ra illuminate the instrument dials of Soviet tanks used by Iraq during Operation Desert Storm (FSTC, 1993). Americium-141 is used in many home smoke detectors.

Exposure to ionizing radiation exhibits two types of health effects: "threshold" (deterministic) and "non-threshold"(stochastic). The severity of a deterministic effect depends on the amount of exposure above a threshold. Below the threshold dose, no acute effects are observed. Normal skin burns are analogous to deterministic radiation effects. Specifically, a burn is first noticeable at a discrete threshold. As the temperature or length of exposure increases, the burn becomes more severe. A burn will occur

Table 6-1. Comparison of the Relative Radiation Dose per Unit Mass Internalized, for DU and Other Substances

ISOTOPE	RELATIVE RADIATION DOSE*
DU†	1.0
Naturally Occurring Uranium†	1.7
^{226}Ra	200,000
^{241}Am	30,000,000

* Doses were calculated based on the committed effective dose equivalent per unit intake factors for inhalation quoted in EPA's Federal Guidance Report No. 11 (Eckerman et al., 1988).

† Uranium doses were calculated assuming that all were insoluble and, as such, represent worst case (highest) committed effective dose equivalent values.

each time the process is repeated (ICRP, 1984). Deterministic radiation effects include radiation sickness and burns. These both require high doses (greater than 100,000 to 150,000 mrem) delivered at high dose rates (minutes to days). Deterministic effects are not important for DU because of their low-radiation dose rate.

Statistics and the associated inferences concerning the probability of occurrence are only as accurate as the sample size from which they are derived. Large sample sizes yield greater levels of confidence in the projection of probability. Therefore, the demography of large human populations is required to detect stochastic health effects with any significant degree of confidence. Cancer and genetic (hereditary) diseases are endemic in all human populations. The probability of occurrence for these types of diseases can be estimated using probability theory. If the probability of occurrence for a cancer or genetic disease increases in populations exposed to radiation, the increase is termed a stochastic health effect. Thus, an increase in the radiation exposure raises the probability of disease (BEIR, 1980, 1990; UNSCEAR, 1988, 1994). Stochastic health effects exhibit the following characteristics:

- An increase in exposure raises the incidence of a naturally occurring disease but the severity of the disease is not related to the level of exposure.
- No exposure threshold.
- All exposures, regardless of the source or strength, contribute to the risk.
- In a single person it is medically impossible to determine the true cause of a stochastic health effect.

Potential radiological health effects from external DU exposure are small. However, personnel must understand the potential hazards of DU, and the Army must continue to effectively manage DU in the inventory.

The primary external hazards from DU are β and γ radiation. These emissions are generated by the radioactive decay of trace-levels of uranium daughter products. The radiation exposure that Army personnel receive depends on the amount of DU present, the DU component (kinetic energy penetrator, DU armor, etc.), the configuration (in manufacture, in storage, uploaded on a vehicle, bare penetrator, etc.) and the exposure time. All DU weapon systems used by the Army are shielded to control the β radiation emitted from DU. The Army has aggressive programs for managing the radiation exposure potential from DU munitions and tank armor. Researchers have conducted investigations to evaluate radiation field strengths (Bratlett et al., 1979; Gray, 1978; Haggard et al., 1986; Hooker and Hadlock, 1986; Hooker et al., 1983; Mishima et al., 1985; Parkhurst et al., 1988, 1991; Parkhurst and Hadlock, 1990; Parkhurst and Sherpelz, 1993; Wilsey et al., 1993). These investigations sought to define the level of exposure for soldiers and other personnel operating or maintaining these weapon systems.

Danesi (1990) summarized the exposure potential from DU weapon systems. He concluded that intact DU weapon systems, both munitions and armor, presented very little external exposure risk for personnel working with them. Danesi (1990) further suggesed that soldiers and support personnel working with or using DU weapon systems are unlikely to exceed the exposure limit for the general population and will not approach the limit for occupational exposure (5,000 mrem/yr). The Army monitors soldiers and support workers according to NRC occupational exposure standards (10 CFR 20.1201).

Holding a spent DU penetrator (DU metal without shielding) would deliver a skin dose (β and γ) of approximately 200 mrem/hour (Coleman et al., 1983; Cross, 1991; Needham and Coggle, 1991; Piesch et al., 1986; Rohloff and Heinzelmann, 1986). The current occupational exposure radiation dose limit (β and γ) for skin is 50,000 mrem/yr. The only plausible way that a soldier or support person could exceed this skin dose would be if a piece of DU from an expanded penetrator were carried as a souvenir.

The radioactive properties of DU have the greatest potential for health impacts when DU is internalized. DU can be internalized through inhalation or ingestion. Inhalation can occur during DU munitions testing, during a fire involving DU munitions or armor, and when DU particles are resuspended by testing or fires. The inhalation potential of a particle depends on its dimensions and mass. The effective particle size is determined from the mass-mean particle size and the surface-mean particle size. Ingestion occurs primarily from hand-to-mouth transfer or from DU-contaminated water or food. Fragment wounds containing DU metal and contamination of any wound with DU occur in combat.

Internalized DU delivers radiation wherever it migrates in the body. Within the body, a radiation is the most important contributor to the radiation hazard posed by DU. The radiation dose to critical body organs depends on the amount of time that DU resides in the organs. When this value is known or estimated, cancer and hereditary risk estimates can be determined (ICRP, 1977).

The health risks of internal DU exposure are a function of the particle characteristics, route of exposure, duration of exposure, and the species of DU (Eckerman et al., 1988; ICRP, 1981). The rate at which DU is eliminated can be measured in the urine or, in the case of ingestion, in the feces. These data can be used to estimate the total amount of DU internalized. From this and other information, researchers can develop health risk models to estimate health risk for various types of internal DU exposure (Boecker et al., 1991; Eisenbud, 1987; ICRP, 1981, 1979; Kathren and Weber, 1988; Kocher, 1989; Leggett, 1989; Toohey et al., 1991; Wrenn et al., 1985).

6.1.2 Health Risks from Chemical Toxicity

Because the radioactivity of DU is very low, the chemical toxicity of DU may be the more significant contributor to human health risk. As previously indicated, DU and natural uranium have essentially the same chemical behavior and toxicity. Therefore, chemical toxicity data developed for any isotope of uranium are applicable to DU. Other heavy metals—such as lead, chromium, tungsten and uranium—are also chemically toxic. The toxic properties of DU and uranium have been broadly studied (Voegtlin and Hodge, 1949, 1953; Stokinger et al., 1981; Kathren and Weber, 1988; Leggett, 1989; Diamond, 1989; Kocher, 1989; Zhao and Zhao, 1990). Danesi (1990) contrasted the potential toxic effects of DU and tungsten when each was used in projectiles. While DU is more toxic than tungsten, Danesi noted that there were substantial data gaps concerning the

toxic behavior of tungsten when alloyed with nickel, cobalt or iron.

As a means of comparison, Table 6-2 presents OSHA workplace time weighted average values for several airborne metals. These concentrations are considered to be acceptable exposure levels in the workplace over a normal working lifetime. Uranium and tungsten are the primary metals of interest in the table; however, all the other metals are used or have been used as alloys in DU penetrators or tungsten penetrators or both (29 CFR 1910.1000, 1910.1025). Toxicity is only one of the variables used in evaluating the risks from DU in the environment. Solubility and route of exposure are also critical. If the material does not migrate in the environment then the exposure potential is reduced and thus the impact of inherent toxicity is moot since the exposure potential dominates the calculation of the risk.

Table 6-2. Comparison of the OSHA Time Weighted Average Values for the Elements Listed for Inhalation Exposures

Element	Soluble Compounds (mg/m^3)	Insoluble Compounds (mg/m^3)
Uranium	0.05	0.2
Tungsten	1.0	5.0
Nickel*	0.1 (0.05)	1.0 (0.05)
Cobalt†	0.05	0.05
Lead	0.05	0.05
Molybdenum	5.0	10.0
Titanium Dioxide	--	10.0

* The values in parentheses are the current recommended values and are based on recent data indicating that nickel is a carcinogen.

† The cobalt values are based on the carcinogenicity of this element and some of its compounds.

The following conclusions can be made from Table 6-2 concerning the toxicity of heavy metals:

- Toxicity and health risk are related to metal solubility.

- Tungsten, lead and DU are chemically toxic.

The toxicity of a penetrator material is determined by the base metal and the alloy metals. DU and naturally occurring uranium act identically in terms of chemical toxicity. The differences between DU and naturally occurring uranium are only observed when evaluating radioactive behavior. Every human ingests and inhales uranium. The amount of uranium internalized varies by geographic location. A typical range for the total mass of uranium in a person is 50 to 150 µg (Stokinger, 1981; Wrenn et al., 1985). Table 6-3 shows:

- Estimates for uranium ingested and inhaled from natural sources.

- Total amount of uranium in the human body.

- Concentration in selected human organs.

- Urinary and fecal excretion rates for uranium**.**

When DU is incorporated in the body, the soluble components migrate throughout the body. Uranium concentrates in the bone, kidney and liver. The kidney is the most sensitive organ to DU toxicity (Kathren et al., 1989; Stokinger, 1981; Wrenn et al., 1985). Human epidemiological studies of workers in the uranium mining and milling industries suggest that nephrotoxicity is the primary chemical toxicity concern. Other human organ systems are less sensitive to the effects of uranium than the kidney

Table 6-3. Uranium Content of the Body from Natural Sources

SOURCE	AMOUNT
Daily intake - ingestion (food and liquids)	1.9 μg/day
Daily intake - inhalation	7×10^{-3} μg /day
Total uranium in the body	90 μg
Uranium kidney concentration	4×10^{-4} μg/g
Uranium liver concentration	2×10^{-4} μg/g
Uranium bone concentration	5×10^{-3} μg/g
Urinary excretion rate	0.05 - 0.5 μg/day
Fecal excretion rate	1.4 - 1.8 μg/day

ICRP Publication 23, 1975; Wrenn, 1985

(Waxweiller et al., 1981; Waxweiller et al., 1983; Thun et al., 1985). For these reasons, the kidney has been broadly accepted as the critical organ for uranium toxicity. The solubility of any uranium compound that enters the body plays a central role in the dose rate of uranium delivered to the kidney, which is related to toxic renal effects (Moore, 1984; Novikova et al., 1963). Uranium species that are readily dissolved in the body's fluids and mobilized in the circulatory system are potentially more damaging than insoluble uranium species. The majority of the uranium that reaches the kidney does so in a soluble form.

In the kidney, uranium binds to bicarbonate and proteins (found in blood and urine). This reaction plays an important role in the mechanism of uranium nephrotoxicity. At normal blood and body pH levels, most soluble uranium is bound to bicarbonate, with lesser amounts bound to

serum proteins (Moore, 1984, Stevens et al., 1980; Wrenn et al., 1987). This binding helps prevent soluble uranium from interacting with most body tissues.

When the bicarbonate-uranium complex enters the kidney, it leaves the blood and becomes part of the freshly made urine found in a specialized renal collecting system called the renal tubules. The renal tubules generally have a more acidic environment than the rest of the body. As a result, the uranium is freed from the bicarbonate and is then able to bind with, and potentially damage, the tissues of the kidney (Stevens et al., 1980, Barnett 1949; Wrenn 1987).

The accepted threshold level for kidney toxicity of 3 µg of uranium per gram of kidney mass was set by the ICRP in 1959 and is still used to establish uranium standards (Diamond, 1989; ICRP, 1960). There is considerable discussion in recent literature concerning this limit, because the basis for choosing 3 µg/g is unclear. Animal data indicate that toxic effects may occur at much lower levels (Kathren and Weber, 1988; Stokinger, 1981; BEIR, 1988; Leggett, 1989; and Diamond, 1989). There is general agreement however that the threshold in humans is between 1 and 3 µg/g for acute, short-term exposures (Kathren and Weber, 1988). The level at which chronic (lifetime) exposures can produce clinically significant end points is not as clearly defined (BEIR, 1988).

Work with animal models (rats and mice) shows the potential for chemically–induced teratogenic effects when the mother is exposed to high levels (approaching levels toxic to the mother) of uranium (BEIR, 1988; Domingo et al., 1989a, 1989b, 1989c). Effects ranged from low birth weight to skeletal abnormalities for doses at which the mother exhibited signs of chemical toxicity. The effects noted are believed to be chemically induced because estimated radiation exposure was too low (all less than 7 rads) to account for the anomolies noted (BEIR, 1988). Extrapolation of these results to human exposures is difficult because of

the limited amount of data on the placental transfer of uranium (BEIR, 1988). There is substantial information available on the placental transfer of plutonium–239; however, the chemical differences are such that a direct extrapolation is not possible.

6.2 Reducing DU Toxicity

DU is inherently toxic. This toxicity can be managed but it cannot be changed. The Army uses good management practices, material control and encasement to limit personnel exposure to DU in armor and munitions.

6.2.1 Reducing DU Radiological Hazards

Technologies are available to reduce the ^{234}U and ^{235}U residuals in DU. These processes are very expensive and would not significantly reduce the radiation risks of DU to health or the environment. Current enrichment processes reduce the concentration of ^{235}U and ^{234}U by 71 and 82 percent (by weight), respectively. This reduction makes DU approximately 60 percent as radioactive as natural uranium (0.4 µCi/g compared with 0.7 µCi/g). Removing all the ^{234}U and ^{235}U (which is not possible) would reduce the specific activity of DU to 0.33 µCi/g (the specific activity of pure ^{238}U). If this were possible, the resulting DU would be about half as radioactive as natural uranium.

6.2.2 Reducing DU Chemical Hazard

There is no known way to reduce the chemical toxicity of DU in the body. Technology cannot significantly affect the solubility of uranium oxides formed in an uncontrolled environment such as the battlefield or in a fire. When munitions are fired or burned and when armor is pierced during battle, DU released to the environment will react with other nearby elements. These chemical reactions may produce compounds with various chemical toxicities. While fires and high-energy penetrator impacts occurring in an uncontrolled environment result in uncontrolled

dispersion of DU contamination, the potential toxicity of this contamination can be limited by preventing DU exposure. Disrupting pathways of exposure can be achieved through personnel training, decontamination procedures and personal protective equipment**.**

The solubility and particle size of the DU species inhaled or ingested controls the impact of its toxicity. The body will excrete much of the soluble uranium within a few days; however, the kidney may be damaged by uranium ions, freed from the bicarbonate form, in the uric acid. This damage mechanism is supported by studies that show animals with alkaline urine have an increased rate of uranium excretion and a decreased level of uranium nephrotoxicity (Wills, 1949). This occurs because alkaline urine has high levels of bicarbonate, which stays bound to the soluble uranium and prevents it from interacting with renal tissue. Alkalization of urine provides a theoretical means of treatment for persons with high levels of soluble uranium in their bodies. By increasing the rate of DU elimination, uranium is prevented from binding to kidney tissue. This procedure has not been clinically demonstrated in humans.

Animal data also suggest that certain chelators, a group of medications used to help remove heavy metals from the body, are effective in removing uranium (a heavy metal). These types of medications have not been used to treat humans exposed to uranium.

6.2.3 Hazard Reduction Using Alternative Materials

Replacing the DU in weapon systems with a non-toxic material would mitigate the health risks associated with DU. This material, however, would need to meet the performance criteria for armor and munitions. It would also need to provide a substantial reduction in toxicity over DU. Tungsten is the only alternative material currently under

evaluation as a substitute for DU. The RDT&E efforts have not successfully developed tungsten munitions or armor that perform at a level equivalent to DU. Furthermore, as previously indicated, tungsten is a toxic heavy metal which would present risks from chemical toxicity similar to DU.

6.3 Medical Evaluation of the Effects of DU

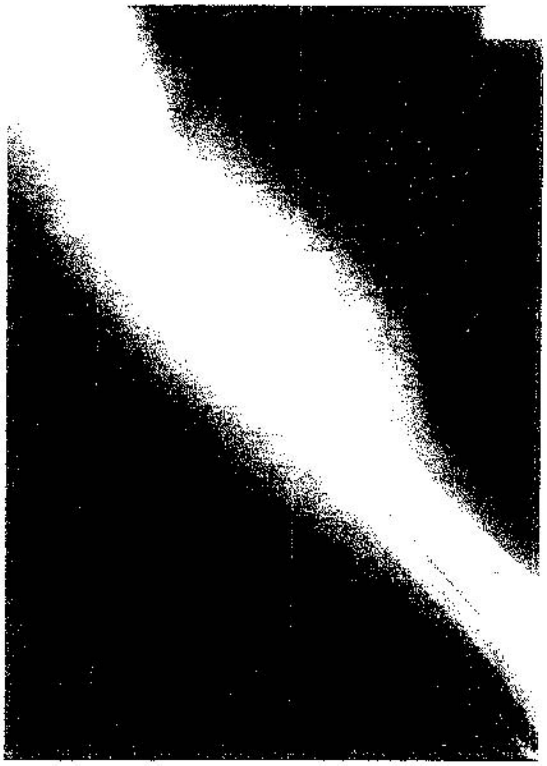
6.3.1 Embedded DU Fragments

Thirty–six soldiers wounded during Operation Desert Storm were reported to have wounds involving embedded DU fragments [General Accounting Office (GAO),1993]. Many of these fragments were not removed using standard surgical guidelines because the risks of surgery were too great (GAO, 1993; Daxon and Musk, 1992). These guidelines were established based on experience with standard (non–uranium, non–radioactive) fragmentation injuries. Figure 6–1 illustrates the surgical difficulty associated with fragment removal.

Concern over the potential long term health effects of embedded DU fragments led the Army's Surgeon General to request that the Armed Forces Radiobiology Research Institute (AFRRI) conduct an in-depth analysis of this issue (DA, 1992). The AFRRI review (Daxon and Musk, 1993) found no compelling evidence to change current surgical criteria for fragment removal. Uncertainty about the long-term health effects of embedded DU fragments warrants long–term follow–up of these patients and further research. Specific uncertainties include chronic chemical toxicity and the effects of long–term, low–dose rate irradiation of the tissues surrounding the fragment, including the potential for carcinogenesis.

Figure 6-1. Embedded DU Fragments

20 mm DU fragment



Multiple embedded DU fragments

The Army Surgeon General has taken the following actions to develop a medical support program for soldiers who may have received DU fragment wounds (Myers, 1993):

- Screening of Army medical records to identify soldiers who might have embedded DU fragments (Myers, 1993).

- Convening a panel of experts from DoD, Department of Veterans Affairs (DVA) and the private sector to develop a protocol for long-term monitoring of soldiers with confirmed or suspected DU fragment wounds (Daxon, 1993b).

- Entering in an agreement with DVA to execute this protocol at the Baltimore DVA Medical Center.

Thirty-six patients were identified for evaluation and monitoring in the Baltimore DVA protocol. Three candidates declined to participate. Of the remaining 33 patients, 15 have elevated levels of uranium in their urine. This indicates that the DU from the fragments is being solubilized in the body and transported to the kidney in the bloodstream (Keogh, 1995). Natural background uranium urine excretion rates are typically 0.6 µg/day (ICRP, 1975). Threshold-toxic uranium urine excretion rates are typically 1000 µg/day (BEIR, 1989). The highest concentration measured among the patients in the Baltimore DVA study was about 50 µg/day. While this urine uranium level was well above background, it was well below typical threshold-toxic excretion rates. To date there has been no indication of adverse health effects caused by the chemical or radiological attributes of DU in this patient sample (Keogh, 1995). Monitoring will continue on these patients.

The Defense Authorizations Bill for fiscal year 1994 (Defense Authorizations Bill, 1993) directed the study of "...the possible short–term and long–term health effects of exposure to depleted uranium including exposure through ingestion, inhalation, or bodily injury...". The AFRRI and the Inhalation Toxicology Research Institute, Albuquerque, N.M. are currently working on projects initiated by the Army Surgeon General resulting from the Defense Authorizations Bill. The AFRRI has initiated pilot studies to evaluate the chemical toxicity, fetal effects and metabolic behavior of embedded DU fragments (Daxon, 1995). The Army Surgeon General should continue to support these and other studies that seek to better define the medical significance of embedded DU fragment wounds.

6.3.2 DU Wound Contamination

Soldiers who are wounded in an environment contaminated with DU are likely to have DU particles in their wounds (Rokke, 1993; Melanson, 1993; Daxon, 1993a). Regular wound cleaning procedures should be effective in managing DU wound-contamination. However, they could be improved through the use of radiation detection equipment. Standard Army radiation detection equipment (AN/VDR-2) or other relatively inexpensive, commercial, radiation detection equipment can be used to assess removal of DU during wound cleaning or to detect DU contamination remaining in a wound (Rokke, 1993). This instrumentation could also be used to assist in screening personnel wounded by DU containing-materials.

6.3.3 Assessment of the Amount of DU Internalized

During Operation Desert Storm, the Army did not assess the level of DU that soldiers internalized until well after hostilities ended (GAO, 1993). The Army Surgeon General recommended that procedures be implemented for medical personnel to assess internalized DU in patients who might be exposed during operations in Somalia. There were no DU exposures during the Somalia deployment. The Army should formalize and continue this policy because:

- Immediate assessment of DU levels can help medical personnel assess the potential for chemical toxicity.

- Medical personnel need initial and follow-up measurements of internalized DU to accurately estimate radiation exposure. If medical personnel compare initial and follow-up results, they can estimate soluble and insoluble fractions of the internalized DU. Because the body eliminates much of the soluble internalized DU within a few

days, delays in sampling exposed personnel reduce the accuracy of DU-exposure estimates.

- Personnel inside or near vehicles struck by DU penetrators could receive significant internal exposures. Army investigations indicate that personnel inside DU struck vehicles could receive a dose in the "tens of milligrams" range due to inhalation (Fliszar et al., 1989). Measuring the quantity of DU a soldier internalized, as soon as practical after initial exposure, would improve the Army's ability to subsequently determine the significance of the exposure.

6.3.4 Medical Training and Guidance

The Army learned several lessons from the unfortunate DU friendly fire incidents during Operation Desert Storm. Early data (JTCG/ME, 1974) estimated the probability of surviving a DU-penetrator hit to be very low. In Operation Desert Storm at the first real combat data point, survivability was more than 90 percent for M1A1 tank crews and more than 80 percent for Bradley crews. While the high rate of survival was fortunate, the inaccuracy of the initial estimate presented medical personnel with the unexpected challenge of developing protocols for treating DU wounds.

Since DU weapons are openly available on the world arms market, DU weapons will be used in future conflicts. The Army will be required to treat soldiers with DU contamination in future conflicts. Therefore, additional guidance is required for medical personnel on treatment of embedded DU fragments, decontamination of wounds and necessary procedures to quantify the DU internalized. The Army Surgeon General provided interim guidance when the Army deployed DU-armored vehicles and DU munitions to Somalia (DA, 1993d). The guidance addressed fragment removal and procedures required to document exposure levels for personnel who may have internalized DU.

In evaluating the issues concerning DU use during Operation Desert Storm, GAO stressed the need to educate personnel in the radiological and toxicological properties of DU and in the methods required to treat patients with internal contamination (GAO, 1993). Broad DU-related training requirements are addressed in Section 6.5 and elsewhere in this report. The medical issues of importance include the following:

- The number of DU patients on future battlefields probably will be significantly higher because other countries will use systems containing DU.

- This is the first time the Army has treated casualties with DU wounds. Military medical personnel have very little experience dealing with DU-fragmentation wounds, DU-wound contamination or DU inhalation. Standard tests for kidney toxicity might not detect early signs of kidney damage caused by DU internalization (Daxon and Musk, 1992). Therefore, more sensitive kidney function tests may be required to adequately evaluate the impact of this type of combat injury (Daxon, 1993b).

- The OTSG and DVA must make wounded soldiers fully aware of the risks from internalized DU and put these risks in perspective. During and after Operation Desert Storm, wounded soldiers and the medical personnel who treated them experienced a high degree of anxiety due to the fear of radiation exposure (Daxon, 1993b). A frank discussion of the radiation risks presented by DU, including the uncertainties associated with embedded fragments, will help allay such fears.

The health risks from DU should not become an issue until after a patient's immediate medical needs have been addressed. A soldier contaminated with DU poses no special hazard to patient care providers. Normal attention to antiseptic and infection control procedures is adequate to

protect medical personnel from DU intake. Soldiers can internalize other toxic substances in a combat environment that present greater health risks than DU. Higher level risks must not be neglected or downplayed because of internalized DU. Higher level risks than those posed by DU must receive higher patient care priority.

6.4 Potential Hazards and Protective Measures

The Army has conducted numerous investigations over the past 25 years concerning worker and soldier exposure to DU. This section provides a summary of some pertinent investigations. Note that the various measuring units reported here (rads, rems and roentgens) and different estimates of annual training or work hours reflect different assumptions made by the investigators in the original studies. For describing exposure from gamma and X-rays, a roentgen is essentially the same as a rem. Dose units are reported in the units used in the respective citations.

6.4.1 Army Depot Workers

Some Army depot workers routinely work with weapons containing DU components. Virtually all radiation exposure from DU in munitions and armor is due to low-levels of gamma radiation emitted by the daughter products formed from the radioactive decay of DU. Munition storage containers are designed to minimize penetration by α and most β particles.

The Battelle PNL measured the dose rates from single pallets of DU munitions and for palletized munitions arranged as they would be in storage (Parkhurst et al., 1993, 1994; ARDEC, 1991a). For large caliber munitions (120 and 105 mm) the dose rates in storage areas with multiple pallets can exceed 1 mrem/hr. The highest dose rate was measured between two rows of M829A2 120 mm munitions,

configured as they would be in a storage facility, at 1.24 mrem/hr. The highest dose rate measured, for the small caliber M919 25 mm munitions, was 0.108 mrad/hr in the spaces between multiple pallets. Personnel working in these facilities are required to follow procedures that minimize exposure as not to exceed the monitoring limit of 500 mrem/yr. These procedures include:

- Periodic radiological surveillance of storage and work areas.

- Oversight by installation RPOs.

- Local inventory accountability of ammunition items containing DU components.

- Inspections by designated Army officials.

6.4.2 Armor Combat Crews

Bradley Fighting Vehicle crews and Abrams Tank crews spend different amounts of time conducting training and maintenance in and on their vehicles. The NRC requirements do not apply in combat (DoDI, 1989). However, the Army is committed to maintaining the safest possible environment for the soldier.

Bradley Fighting Vehicle Crew Exposure

The Fighting vehicle crews have annual occupancy rates of 845 hours for the M2 (Infantry) Bradley Fighting Vehicle and 1,109 hours for the M3 (Cavalry) Bradley Fighting Vehicle (Hixon, 1990). DU munitions are not part of a combat vehicle's basic load during field maneuvers or gunnery training. DU munitions are not authorized for training issue by the Standards in Training Commission (STRAC) and are not available for allocation/requisition, as specified in DA Pam 350-38, *Training Standards in Weapons*

Training, February 15, 1993. Therefore, training in U.S. combat vehicles should not result in increased DU exposure.

In combat, the Bradley Fighting Vehicle will carry M919 25 mm DU ammunition. The Battelle PNL estimated that the highest dose to personnel in the Bradley (scout configuration M3A3) was 0.18 mrad/hr (Piper et al., 1993). At this dose rate a combat crew would not exceed the NRC 5,000 mrem/yr occupational radiation exposure limit if they stayed in the vehicle continuously (24 hr/day) for a year (Parkhurst, 1994a; Piper et al., 1993).

Abrams Tank Crew Exposure

A report published by the U.S. Army Ballistics Research Laboratory estimated that tank crews spend a maximum of 904 hours in combat vehicles during a training year (Fliszar et al., 1989). Tank crews also use their vehicles to rest, sleep, eat or pass the time, particularly in wet or cold weather.

The M1A1HA tank contains DU armor. With a full combat load mix of ammunition, the tank commander, gunner and loader each receive a radiation dose of 0.01-0.02 mrem/hr. The driver receives a radiation dose of 0.13 mrem/hr to his head if armor is overhead or 0.03-0.05 mrem/hr if ammunition is overhead. The same exposure exists for the M60A3 tank driver and the M1 and M1A1 (non-DU armored) tank driver when ammunition is overhead (ARDEC, 1990; Parkhurst and Scherpelz, 1993, 1994; Wilsey et al., 1993).

It is unlikely that either the 500 or 100 mrem/yr exposure level will be exceeded for either tank during peacetime or wartime operations. However, more detailed estimates of the amount of time crews spend in their tanks should be obtained to verify this assessment. The TACOM is

in the process of obtaining these estimates for the following (Gryna, 1994):

- Tanks without DU armor, crew occupancies of more than 1,600 hrs/yr are required to exceed the 100 mrem/yr limit and almost continuous occupancy (over 8,300 hrs/yr) to exceed 500 mrem/yr using the highest dose rate (0.05 mrem/hr) measured (Gryna, 1994). With the exception of the vehicles in Korea, tanks are not uploaded with DU munitions during peacetime operations. Applying current estimates of the tank occupancy times during peacetime training (from 700 to 900 hrs/yr) to operations in Korea, translates into a maximum exposure of between 40 and 55 mrem/yr (Parkhurst and Scherpelz 1993, 1994). These are well below 100 mrem/yr. While estimates of occupancy times for combat operations are not available, they will not exceed 8,300 hrs/yr.

- Tanks with DU armor, crew occupancies of 770 hrs/yr are required to exceed the 100 mrem/yr limit and over 3,800 hours to exceed 500 mrem/yr using the highest dose rate measured (0.13 mrem/hr) . Given the variability of the exposure rate to the driver as a function of the driver and gun tube position (varies from approximately background <0.02 mrem/hr to 0.13 mrem/hr), the average exposure rate will, more than likely, be substantially less than 0.13 mrem/hr. How much less cannot be determined until the TACOM study is complete.

Possible Exposure to DU in Gun Bore Gases and Fragments

When an Abrams main gun or a Bradley 25 mm cannon is fired, some burnt gases enter the crew fighting compartment (PM TMAS, 1993). A bore evacuator removes these gases from the end of the Abrams main gun after each round is fired (FM 17-12-1). Blowers and nuclear, biological and chemical (NBC) protection systems in the Abrams and

Bradley ventilate the crew compartment (FM 17-12-1; TM 9-2350-252-10-2; TM 9-2350-284-10-2).

A small amount of DU oxidation may occur in the gun tube when a DU round is fired (Parkhurst, 1993; McGuire, 1993d; PM TMAS, 1993). Also, a small amount of DU is expelled when a DU round is fired (Mishima et al., 1990; Parkhurst, 1993; PM TMAS, 1993). Abrams and Bradley gun tubes and the bore evacuator of the Abrams may contain small DU residuals after firing various DU munitions (Mishima et al., 1990; Parkhurst, 1993; YPG, 1993; Elliott, 1993; NRC, undated; AMC, 1993). Measurements indicate that radioactivity is detectable but within NRC standards (Davis, 1993a).

When a DU projectile breaks up in a gun tube, DU contamination is concentrated near the end of the tube. The AMC tested the Bradley 25 mm gun to determine if this contamination migrates from the gun tube into the crew compartment. A draft study by Battelle PNL indicated that firing DU ammunition with a number of inbore breakups occurring produced a detectable level of DU aerosol particles in the crew compartment. Some of these particles were within the respirable range, but the concentration was within NRC guidelines (Parkhurst, 1993).

During September 1993 and February 1994, AMC tested DU migration into the Abrams tank turret. No DU intrusion was noted, even when the testing crew deliberately created flarebacks.

Possible Exposure to Soldiers Near DU-Contaminated Vehicles

Army field tests have shown that if a DU penetrator strikes a DU-armored vehicle and creates a fire or an explosion, it can contaminate nearby soil. Most of the DU contamination detected in these tests was within 5 to 7 m of the vehicle (4.7 µg of DU per gram of soil following five

tests at the same location) (Fliszar et al., 1989). DU contamination decreased to less than 0.5 µg/g of soil at 30 m. To put this contamination in perspective, the normal uranium content in soil is about 5 µg/g of soil (NCRP, 1987c). During these tests, some DU armor components were expelled 76 m from the vehicle. Soil contamination created by these tests did not require treatment or removal under NRC criteria (Fliszar et al., 1989).

6.4.3 Maintenance and Recovery Personnel

Vehicle maintenance and recovery personnel may be exposed to DU and other toxic substances in combat-damaged vehicles. The Army has not assessed the risks to recovery and maintenance personnel working in and around vehicles contaminated with DU particles. Inhalation and ingestion present a potential pathway for internalization of DU by these personnel. Good personal hygiene reduces the potential for hand-to-mouth internalization. The Army needs to further evaluate these risks and define appropriate protocols.

DU-contaminated vehicles that present the highest risks for maintenance and recovery personnel fall into three categories:

- Abrams tanks with DU armor uploaded with DU ammunition, that were penetrated by a DU projectile and then burned. This situation presents the greatest risk because the presence of both DU armor and rounds provides a large amount of DU metal from which particles can be generated. A penetrator strike and subsequent fire can convert the DU metal to aerosol particles.

- Burned vehicles uploaded with DU rounds (either with or without DU armor). In burn tests of DU-armored vehicles uploaded with DU munitions, fire did not expose

intact DU armor. Only the burned DU ammunition caused contamination in these tests.

- Vehicles containing ammunition (DU and/or conventional), but without DU armor, that were struck by DU penetrators and did not burn. The maximum amount of DU present inside such a vehicle would be the total mass of the penetrators striking the vehicle (plus any DU ammunition the vehicle may have contained).

The BRL performed the most direct study of DU hazards to maintenance and recovery personnel (Fliszar et al., 1989). They conducted a health physics analysis of airborne and soil DU contamination as an add-on experiment to a performance test of DU armor. The performance testing involved striking a DU-armored tank uploaded with DU rounds with several types of munitions (including DU penetrators). In one test the penetrator entered the crew compartment. Another test caused a fire that burned DU munitions uploaded in the vehicle. Both of these tests significantly contaminated the crew compartment. When personnel entered the crew compartment after the breakthrough and the fire, airborne contamination was within NRC standards for non-occupational workers. Unfortunately, this study did not evaluate the resuspension of dust that would occur when maintenance and retrieval personnel entered the damaged vehicle.

BRL attempted to evaluate DU-particle generation as a function of welding on DU-contaminated tank armor (Fliszar et al., 1989). The data confirmed that DU particles were generated during welding but were insufficient to determine their concentration.

BRL evaluated airborne DU exposure when damaged DU-armor packages were removed from the tank turret (Fliszar et al., 1989). This operation involved cutting metal

and using a lift to remove damaged armor packages. Data indicated that airborne contamination generated by this operation could exceed the NRC occupational exposure criteria.

Members of the 144th Service and Supply Company performed maintenance and recovery of U.S. vehicles damaged during Operation Desert Storm, including vehicles contaminated by DU. The Army Surgeon General tasked USACHPPM to obtain voluntary 24-hour specimens from personnel for radiochemical analysis. As of May 1994, preliminary results from 9 of the 26 personnel, at the time of specimen collection, were not positive for DU. Fluorometric analysis was performed at USACHPPM and more sensitive a spectral analyses were performed at a leading DOE laboratory.

Field surveys were conducted in Southwest Asia on vehicles that were contaminated with DU (Rokke, 1993; Lindsay, 1993). Unfortunately, these surveys only classified the vehicles as contaminated or clean. The level of DU contamination was not ascertained.

Combat maintenance and recovery personnel from the 144th Service and Supply Company did not know that some of the vehicles retrieved during Operation Desert Storm were contaminated with DU (GAO, 1993). They had no guidance on the management of DU-contaminated equipment. The Army does not have a technical bulletin addressing procedures for retrieving DU-contaminated equipment during combat.

Peacetime operational procedures for managing DU weapon systems' accidents are outlined in TB 9-1300-278, *Guidelines for Safe Response to Handling, Storage, and Transportation Accidents Involving Army Tank Munitions or Armor Which Contain Depleted Uranium*. However, these protocols were not intended to be applied in combat. This

document describes procedures based on NCRP principles of radiation protection (NCRP, 1987a). U.S. radiation protection policy mandates that radiation exposures are below established standards and are ALARA without placing undue constraints on the industry or mission (3 CFR).

The Army applies the ALARA principle to peacetime accidents involving DU. For example, TB 9-1300-278 recommends that firefighters use respirators. This recommendation is not made because the risks from DU are high, but because respirators reduce the potential for inhalation without increasing costs, hindering firefighting operations or increasing the risk of injury to the firefighters. Most firefighters wear self-contained breathing apparatus at all fires. Conversely, TB 9-1300-278 does not recommend respirators for medical personnel attempting to save lives or to treat serious injury during a DU fire, because the delay in donning respirators would increase risks and exceed the potential benefits.

Combat is not a safe undertaking. The non-radiation risks of combat are significantly higher than the risks used to set radiation protection standards. Combat and DU risks must both be considered when developing a TB for combat operations. Some of the salient issues that must be considered include:

- DU contamination control.
- Radiological monitoring of damaged equipment.
- Screening scavenged parts for DU contamination.
- Recovering unserviceable or burned DU munitions.
- Protective masks, benefits and hazards.

The TB developed for DU control under combat operations should provide for a transition in procedures toward TB 9-1300-278 as contaminated vehicles and equipment become further removed from actual combat. Thus, the Army needs to develop guidance for combat maintenance and recovery operations for DU-contaminated vehicles based on a reasoned application of the risks of combat and the principles of radiation protection.

6.5 Soldier Hazard Awareness Training

The GAO indicated that soldiers need additional training on the use and effects of DU armor and ammunition so that they will not expose themselves to DU oxides while working (GAO, 1993). In addition, the Army should train PEOs and PMs for DU-weapon systems on health and environmental issues associated with the DU-weapon system life cycle.

Before Operation Desert Storm, specific service schools or unit leaders provided some soldiers with limited training on DU. For example, service schools trained explosive ordnance disposal (EOD) soldiers, ammunition handlers and welders who might work on DU armor. Some unit leaders had given their troops limited training on procedures for handling tanks with DU armor that had experienced internal ammunition fires or armor penetration.

Before Operation Desert Storm, the Army had only addressed the hazards and handling of DU in military job-specific and branch-specific publications. As previously mentioned, TB 9-1300-278 provides procedures for handling equipment contaminated with DU. In addition, TM 9-2350-264-10-2, *Operator's Manual: Unusual Conditions, Trouble Shooting and Maintenance, Tank, Combat, Full-Tracked: 120 mm Gun M1A1 (2350-01-087-1095) General Abrams, Volume 2 of 2*, warns of the potential hazards of DU. However, it is

unlikely that most U.S. soldiers would have been aware of these documents. The typical armor, engineer, mechanic, infantry, transportation or medical soldier probably would not have read TB 9-1300-278 in normal training or duty. It is more likely that an EOD specialist, ammunition handler, firefighter, installation RPO or transportation officer would have been acquainted with TB 9-1300-278. Similarly, M1A1 tank crews, and possibly tank mechanics, may have noted the warnings and directives about DU in Volume 2 of TM 9-2350-264-10-2.

Neither FM 17-12-1, *Tank Combat Tables,* nor AR 385-63, *Policies and Procedures for Firing Ammunition for Training, Target Practice, and Combat,* indicates that DU in the ammunition could be hazardous. Appendix G of FM 17-12-1 contains standard procedures for reducing crew exposure to DU oxides when incoming fire ignites munitions stored in a tank's bustle.

Before the GAO study, TACOM had published TM 9-2350-200-BD-1, *Battlefield Damage Assessment and Repair for Tank, Full-tracked: 105 mm Gun, M1 (2350-01-061-2445) and Tank, Combat, Full-Tracked: 105 mm Gun, IPM1 (2350-01-136-8738) and Tank, Combat, Full-Tracked: 120 mm Gun, M1A1 (2350-01-087-1095) and General Abrams (Hull)*. This manual lists the procedures necessary to assess, recover and repair Abrams tanks from the unit maintenance level to the support maintenance level. It also contains an appendix on assessing and dealing with DU contamination.

Operation Desert Storm showed that, in combat, a broad range of military specialties needed to be made aware of the hazards and precautions required when dealing with DU and DU contaminated vehicles (GAO, 1993). Soldiers require training on the hazards of DU, on methods to detect DU, and on field–expedient protection and decontamination measures. Moreover, the Army needs to revise its manuals for weapon

systems that contain DU components so that the manuals clearly identify DU components, potential hazards, and requisite precautions for use and repair. The Army has initiated a program to accomplish these tasks. The Armor School, for example, includes a DU presentation in the Basic Noncommissioned Officer Course, Master Gunner Course, Officer Basic Course and Officer Advanced Course. The Chemical School added DU training to three instruction programs, and the Ordnance School began presenting a hazardous materials briefing that includes information on DU.

The Army is examining DU training requirements for the rest of the force. In July 1993, the Office of the Deputy Chief of Staff for Operations and Plans (ODCSOPS) designated Training and Doctrine Command (TRADOC) as the Army's executive agency for DU training. The ODCSOPS provided guidance to TRADOC for developing training across the Army and tasked TRADOC to recommend a training strategy and implementation milestones by September 1, 1993 (DA, 1993a, 1993b).

Both DA and TRADOC are seeking funds and personnel to support a three-tiered DU training program. Tier one will provide general radiation awareness training for all Army personnel. Tier two will support the AMC contaminated equipment recovery plan. Tier three will provide training for Chemical Corps personnel (Commandant, U.S. Army Chemical School, 1993). The Army recently authorized the Chemical School, to produce two DU training films: One film will provide general awareness training for all the Army. The second film, produced with the Ordnance School, will deal with equipment recovery on the battlefield (Battle, 1994).

Marking of individual items containing DU varies and is sometimes misleading. Tank ammunition is marked with the word "STABALOY," but 25 mm M919 rounds and

M1A1 tanks with DU armor bear no special markings. As a result, soldiers cannot easily identify DU materials. This could lead to accidental exposures of soldiers to the potential hazards of DU, especially in combat. Moreover, using alternate names for DU such as “STABALOY” can lead to confusion and to possible mishandling of DU materials. Standardized markings should be developed.

6.6 Summary

No available technology can change the inherent toxicity of DU or significantly reduce its toxicity.

Like natural uranium, DU presents toxicological and radiological health risks, which depend on the chemical and physical form of the uranium and the duration and mechanism of exposure. Radiological risks from external exposure to DU penetrators are low. Soldiers are internally exposed to DU if they inhale or ingest DU particles, if a DU fragment is embedded in the body, or if DU particles contaminate a wound. Radiological risks from internal exposures are greater than risks from external exposures and cannot be estimated without detailed knowledge of the physical and chemical properties of the DU internalized. DU’s solubility in bodily fluids determines its movement into organs and its elimination from the body. Uranium is chemically toxic if sufficient quantities are internalized. The kidney is the most sensitive organ to uranium. The generally accepted threshold level for kidney toxicity is 3 µg of uranium per gram of kidney mass.

Based on Operation Desert Storm experience, the Army learned that it needs to provide additional medical management guidance on:

- The treatment of embedded DU fragments.
- Decontamination of wounds.
- Procedures necessary to quantify internalized DU.

The Army Surgeon General has commissioned long-term studies to determine the medical significance of allowing DU fragments to remain in the body. For decontamination, medical personnel can remove most DU from wounds using standard medical methods and standard-issue Army radiation detection equipment. DU's chemical and radiological health risks to the patient and the health care provider are sufficiently low so that DU contamination should not be considered an issue until the patient's immediate medical needs have been addressed.

Personnel in or near vehicles when the vehicles are hit by DU munitions are the most likely to receive internal exposures. Recovery and maintenance personnel working in and around DU-contaminated vehicles also can inhale or ingest DU. The potential for internalization is high enough that the Army should further investigate and analyze the risks. Other Operation Desert Storm personnel whose only possible DU exposure was through breathing fumes from burning vehicles or incidental contact with contaminated vehicles are not considered to be at risk by the Army Surgeon General. Studies indicate that tank crews and workers in DU weapons storage areas do not receive external radiation exposures in excess of NRC limits.

Soldiers need additional training on the use and effects of DU armor and ammunition so they will not expose themselves to DU oxides while working. In addition, the Army needs to update its TMs to provide more information on DU. Finally, the marking of individual items containing DU should be standardized and made more understandable.

7 ENVIRONMENTAL RISKS ASSOCIATED WITH U.S. ARMY USE OF DU AND WAYS TO REDUCE THEIR LONG-TERM EFFECTS

The risks associated with DU releases to the environment through U.S. Army activities will be specific to each application of DU and to each site where it is used. Chapter 7 provides a discussion of the mobility, fate and effect of DU in the environment. Laws, regulations, criteria and standards are constantly revised to better manage the discharge contaminants into the environment. However, the basic physical phenomena do not change when the regulatory approach changes. A risk-based management system is the only approach that provides the Army sufficient flexibility to manage DU efficiently in a fluid regulatory environment. It asserts that to develop a formal risk assessment, one must understand the transport and fate of DU and its effects on plants and animals, including man. This chapter also describes how the Army has developed a considerable understanding of DU's behavior in the environment through studies at the three firing sites used for most DU weapons development and testing.

In addition, Chapter 7 discusses remediating sites contaminated with DU and available remediation technologies. Finally, this chapter offers a number of actions the Army can take to cost-effectively protect the environment from the long-term consequences of the use of DU.

7.1 Environmental Transport and Fate

Water is the dominant mechanism of environmental transport of all metals. Metals may move in groundwater or in surface water such as rivers. For metals widely dispersed across the land, the principal concern is groundwater contamination. Runoff also can transport contamination to surface streams and ponds (Ebinger et al., 1990). In an arid environment, wind erosion can transport dust containing DU (Price, 1991). In addition to aqueous transport and airborne transport, biological transport through the food chain can move a contaminant through the environment.

As discussed in Section 2.1.3, although the radiological properties of uranium isotopes differ considerably, their chemical behavior is essentially identical. Thus, in this discussion of the physical and chemical properties of DU in the environment, DU and U are used interchangeably. In the past 50 years, a large body of knowledge regarding the transport, transformation, fate and recovery of uranium has been developed, mostly as a result of uranium mining and milling. Much of this information applies to the environmental problems associated with the use of DU in weapons. Magness (1985) provides a brief summary of the environmental transport and fate of DU. Information that DOE compiled for the Uranium Mill Tailings Remedial Action (UMTRA) Project is particularly valuable. DOE conducted this project in response to the Uranium Mill Tailings Radiation Control Act of 1978. Portillo (1992) describes the UMTRA project, giving particular attention to its history and the technology developed to mitigate impacts of uranium milling operations.

7.1.1 Airborne Transport

Airborne transport of uranium involves particles. Vaporization is not a significant transport route because

uranium metal has a boiling point of 3818 °C. Powdered uranium metal may burn spontaneously in air, but larger pieces of metal, such as penetrators, require a heat source ranging from 700 °C to 1000 °C to produce ignition. A DU projectile creates very fine particles of uranium oxides (typically 75 percent U_3O_8 and 25 percent UO_2) upon impact or burning. These particles settle according to Stokes' Law. The larger particles [> 5 micron (µm)] settle rapidly and travel only short distances through air because they are so dense (specific gravities of 8.3 and 10.96, respectively).

A number of researchers have studied the dispersal of aerosol particles of uranium after a DU penetrator hits a hard target (Mishima, 1990; Jette et al., 1990; Glissmeyer and Mishima, 1979; Fliszar et al., 1989). In addition, Pacific Battelle Northwest Laboratory published studies on this topic in 1979 and 1990. Its 1979 report (Glissmeyer and Mishima) identified several experimental problems that were subsequently resolved, so the second study (Jette et al., 1990) is believed to be more technically defensible. Jette et al. found that approximately 18 percent of a penetrator round dispersed into airborne particles when it hit a hard target. Of the aerosol particles produced by the impact, 61 percent to 91 percent were less than 10 µm in diameter, depending on the type of round. Furthermore, they found a strong propensity for DU particles to resuspend when multiple rounds were fired, but they also found that the resuspended aerosol particles were larger on average than those from the first round fired. Lung-solubility analysis of the particles less than 10 µm in diameter found that 24 percent to 43 percent were class "D," representing a 50 percent dissolution time in simulated lung fluids of less than 10 days. The rest of the particles were class "Y" materials, with a 50 percent dissolution time longer than 100 days.

Fliszar et al. (1989) reported results of firing various penetrator munitions at tanks containing DU shielding under intensively instrumented conditions in open air at the DOE

Nevada Test Site. When the DU penetrator rounds hit a tank, more than 90 percent of the airborne DU remained within 50 m of the tank. During one test, a fire began inside a tank; it was allowed to burn more than 12 hours. Dense smoke from the fire plugged sampling systems disrupting measurements. However, as with the impact tests, airborne transport appeared to be minimal beyond about 50 meters (m).

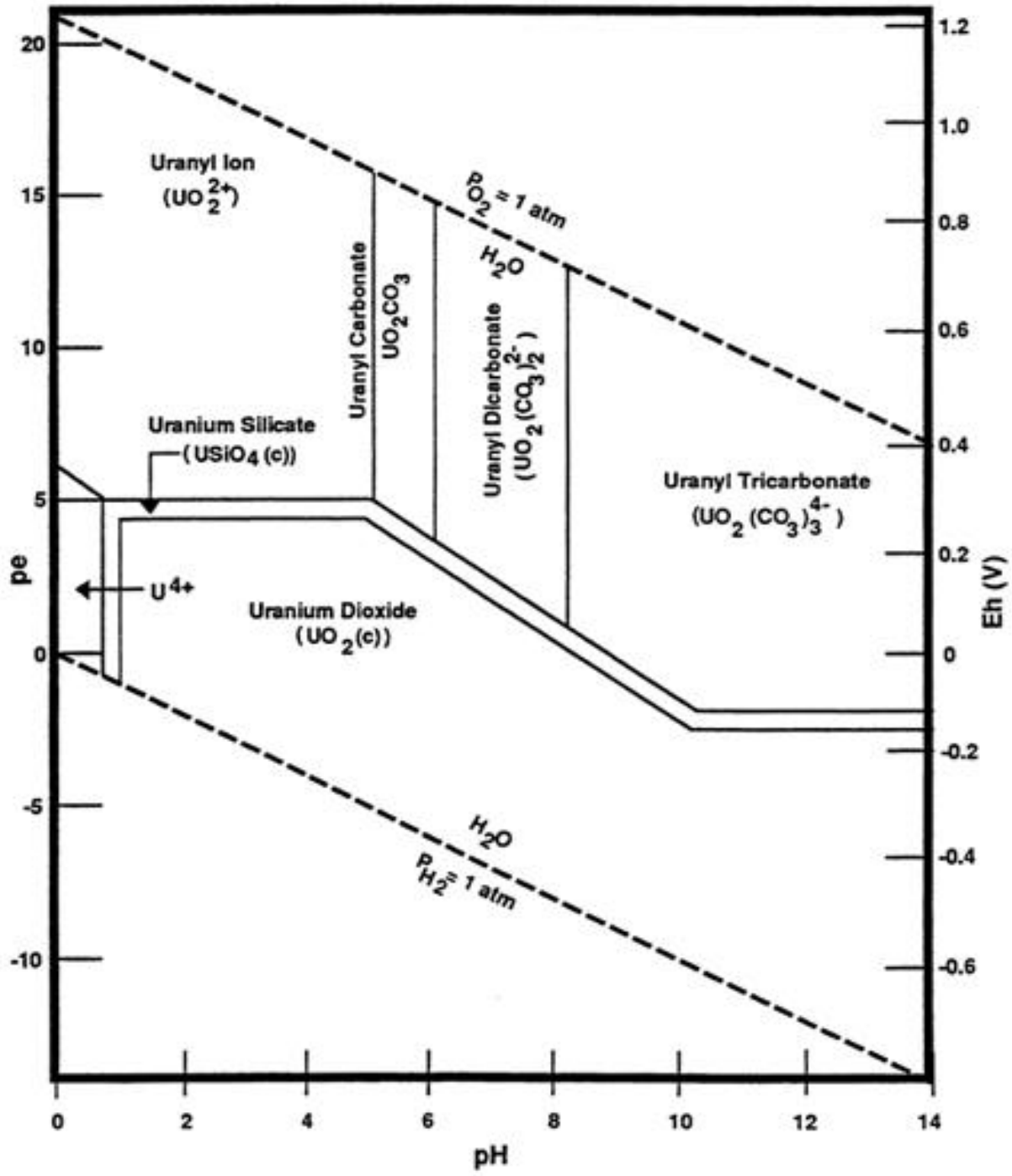
7.1.2 Aqueous Transport

As previously discussed in Chapter 2, DU fragments exposed to the atmosphere will oxidize from DU metal to U(IV) and eventually to U(VI). Uranium is thermodynamically stable only as U(IV) or U(VI). The oxidation rate of DU fragments depends on several factors, including fragment size, pH, humidity, soil moisture content, soil chemistry and oxygen content. Previous studies of the role of aqueous systems on the transport and fate of DU have been conducted by Hanson and Miera (1976, 1978), Ebinger et al. (1990), and Erikson et al. (1990a, 1993).

Figure 7-1 is a pe-pH (electron activity-relative alkalinity of a fluid) diagram for uranium U(IV) and U(VI) species in the environment. It summarizes the acid-base and oxidation-reduction chemistry (commonly abbreviated as redox chemistry) of uranium. The vertical scale (pe) defines the potential for oxidation-reduction reactions, while the horizontal scale (pH) defines acidic or basic conditions.

Low pH values describe acidic conditions, while high pH values represent basic conditions. A neutral solution corresponds to a pH value of 7.0. The diagonal dashed lines on the figure represent the stability limits for water—the limits for equilibrium in environmental systems. Above the top line, water is oxidized to oxygen gas (O_2). Below the bottom line, water is reduced to hydrogen gas (H_2). Brookins (1988) presents a formal discussion of pe-pH diagrams.

Figure 7-1. pe-pH Diagram for Uranium



The pe/pH diagram in Figure 7-1 shows only two solid phases of uranium: uraninite and coffinite. More than 50 uranium-containing minerals have been identified in nature. While it is possible to construct pe-pH diagrams for these other phases, the fundamental result is the same: under oxidizing conditions, uranium is soluble; under reducing conditions, it is insoluble.

Figure 7-1 shows the two uranium oxidation states that can be stable in water. The oxidation or reduction of uranium ions occurs when the pe and pH conditions move into the region of the figure denoted as containing coffinite (uranium silicate, $USiO_4$). Under oxidizing conditions (i.e., above the coffinite region in Figure 7-1), uranium is present as soluble uranyl species U(VI) (oxidation state of +6). In this region under acidic conditions (pH less than 5), the uranyl ion (UO_2^{2+}) is dominant. At higher pH levels, these ions form weak bonds with carbonate ions to form uranyl carbonate, UO_2CO_3; uranyl dicarbonate $UO_2(CO_3)_2^{2-}$; and, above pH 8, uranyl tricarbonate $UO_2(CO_3)_3^{4-}$. Oxidizing conditions (as described above) are present in a free-flowing river or an oligotropic lake. These conditions foster maintenance of the U(VI) soluble form of uranium.

The second uranium oxidation state presented in Figure 7-1 is U(VI) (oxidation state of +4), the insoluble form. This is present under reducing conditions either as the mineral uraninate (UO_2) or as the mineral coffinite ($USiO_4$). When reducing conditions exist, the pe is low (i.e., in or below the coffinite region in Figure 7-1). This normally corresponds to anaerobic conditions typical of deep groundwater and eutropic surface waters such as swamps, wetlands, nutrified lakes, and polluted rivers.

The most important point about this diagram is that oxidizing conditions affect the solubility and mobility of uranium. Under oxidizing conditions, most uranium is in the form of soluble uranyl ions that can move through the environment and living organisms. Under reducing conditions, most uranium is solid or insoluble. Because most soil is exposed to the atmosphere, uranium will eventually become soluble, resulting in its aqueous transport. Thomson et al. (1986) provides a more complete discussion of the redox chemistry of uranium in the environment.

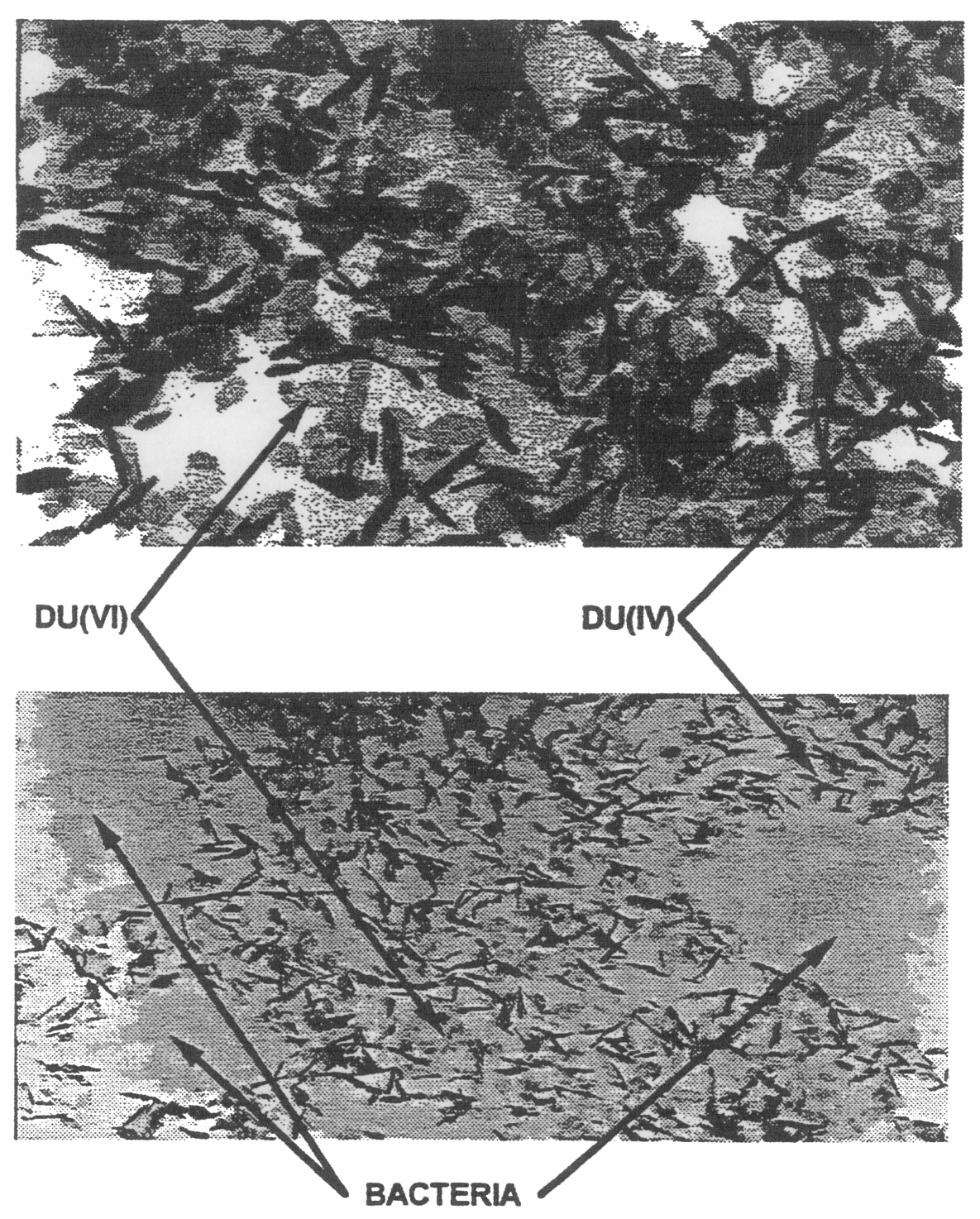
Erikson et al. (1990b) found that weathered DU penetrators principally corroded into hydrated U(VI) oxides that were very soluble in water. Erikson further found that when the native soils were acidic, they could attenuate uranium species, probably through adsorption reactions. In subsequent research, Erikson studied the geochemical factors affecting the environmental fate of DU penetrators in the wet, temperate climate of APG and the extremely arid climate of YPG. This research considered several geochemical factors, including the oxidation of DU metal into more stable oxides, the solubility of the oxidation products, and the interactions of soluble DU species with site-specific soils. Measured corrosion rates were fairly small, ranging from 20 one-thousandth of an inch/year (mils/yr) to 40 mils/yr [0.05 centimeter/year (cm/yr) to 0.10 cm/yr]. Corrosion rates were higher at YPG, probably because the soil contained more carbonate minerals. The corrosion rates in both cases were large enough that they would not limit mobility or aqueous transport of DU. Studies of adsorption of uranium species onto soil found varying sorption capacities among different soils at APG and YPG. The high carbonate soils at YPG had the lowest capacity, probably due to the formation of very soluble uranyl carbonate complexes such as UO_2CO_3, $UO_2(CO_3)_2^{2-}$ and $UO_2(CO_3)_3^{4-}$ (Erikson et al., 1993).

Once present in the environment, soluble U(VI) species can undergo two types of reactions that will reduce their mobility: adsorption and reduction. Adsorption or ion exchange reactions involve attachment of soluble molecules to soil particle surfaces through either covalent bonds (adsorption reactions) or electrostatic bonds (ion-exchange reactions). The two types of reactions are commonly lumped together using the term “sorption reactions.” The sorption chemistry of U(VI) species has not been well studied. Preliminary results, however, suggest strong interactions between uranyl complexes and common soil iron hydroxide minerals (Hsi and Langmuir, 1985).

Under aerobic conditions, iron can play a key role in controlling the movement of uranium through soil. Uranium will bind to many iron minerals under aerobic conditions. Iron and uranium then co-precipitate and remain bound in the soil. In addition to solubility, uranyl U(VI) complexes may be formed by adsorption on minerals or organic compounds in the soil. These adsorption reactions will attenuate uranium species and reduce their mobility, but a quantitative model of this phenomenon for uranium is not presently available. Furthermore, sorption reactions generally do not permanently remove a constituent from solution but rather temporarily bind it reversibly to the soil so it may be released to solution at a later time. Therefore, sorption reactions cannot generally be relied upon as a mitigation mechanism unless the sorbent is physically removed from the system.

The most well-characterized interactions involve adsorption of uranium and other metals onto humic and fulvic acids, large organic molecules resulting from the decay of dead plant matter. The organic content of soils at the surface ranges from less than 1 percent in desert environments to more than 30 percent in loamy soils from deciduous forests in the southeastern U.S. (Jury et al., 1991); however, in deciduous forests, the organic content at 10 cm depth is in the range of 4 percent. Uptake (complexation) by organic compounds will slow the migration of uranium through soil, often by several orders of magnitude, so that it becomes essentially immobile. High concentrations of organic material may also stimulate growth of bacteria that reduce iron and sulfate. These bacteria can reduce soluble U(VI) to insoluble U(IV) compounds, thereby limiting the mobility of uranium. This phenomenon is captured by the electron micrograph presented in Figure 7-2. Additional details on the environmental behavior of DU are available in Erikson et al. (1990a) and Langmuir (1978).

Figure 7-2. Bacteria Reducing Soluble and Insoluble DU



Under anaerobic conditions, U(VI) may be biologically reduced to insoluble U(IV). This process has been the subject of considerable research for more than 10 years. Kauffman inferred microbial reduction of U(VI) by measuring uranium removal as uranium mine wastewater passed through an anaerobic wetland. This process also removed selenium and arsenic, two metals that commonly occur with uranium (Kauffman et al., 1986). In 1991, Lovley et al. first isolated an organism that unequivocally demonstrated U(VI) reduction. A more recent investigation showed that several classes of common microorganisms can reduce U(VI) to U(IV). This investigation produced transmission electron micrographs and X-ray diffraction images of uraninite crystals (UO_2). These results suggest that the precipitates of U(IV) will have very low solubility and will be stable in the environment unless oxidizing conditions are reestablished (Thomson et al., 1994).

7.1.3 Biological Transport

Magness provides a brief review of the impacts of DU munitions testing (1985). In the natural environment, uranium accumulation in plant and animal tissues is a function of uranium bioavailability, which largely depends on the solubility of the uranium species and on the soil chemistry of the area. Magness concluded that uranium is not effectively transported in the food chain, partly because U(VI) species are highly soluble and quickly excreted by organisms low in the food chain. The principal source of uranium in animals appears to be particulates deposited by air or water and eaten with vegetation or incidentally ingested during preening.

In an ongoing study, Los Alamos National Laboratory is conducting ecological risk assessments to determine the human radiological dose from DU munitions testing at JPG and APG (Ebinger, 1993a, 1993b). The study considers multiple exposure pathways, including DU accumulation in soil and plants, livestock drinking

contaminated water, human consumption of contaminated water, DU doses through meat and milk consumption, soil ingestion, dust inhalation, and external exposure to DU particulates. One of the more unusual exposure pathways involves consumption of venison from deer living at the test sites. Los Alamos National laboratory (LANL) is using the residual radiation (RESRAD) computer code and supporting studies to develop recommendations to minimize human and ecological risks at both JPG and APG.

7.2 Effects of DU on the Environment

In DU-contaminated soil, most plant injury occurs in the roots (Hanson and Miera, 1978). Some plants appear to be more tolerant than others to high concentrations of uranium in the soil. These plants may have developed a mechanism for limiting uranium intake. Hanson and Miera (1978) found that uranium concentrations may be significantly less in plants than in the surrounding soil. This observation is consistent with the findings in a study of the environmental impacts of DU munitions testing at Eglin Air Force Base, Fla. Of the 25 vegetation samples collected, yucca roots had the highest apparent uranium concentrations. However, after vigorous surface washing to remove uranium dust, uranium concentrations were too low to be detected in most samples, including yucca roots (Becker et al., 1989).

Because uranium has a low specific activity and most animals in the natural environment do not live very long, the principal hazard associated with animals ingesting uranium is toxicity, not radioactivity. Magness (1985) cites studies that found that, although insoluble uranyl-iron complexes are only slightly toxic to the kidneys, soluble uranium compounds poison the kidney long before any other organ. Burrowing animals appear to be at greater risk for uranium toxicity, particularly in arid environments where alkaline soils may increase uranium's solubility

(Hanson and Miera, 1978). Ingesting DU-contaminated vegetation or water does not appear to significantly affect large grazing animals, presumably because the contaminated vegetation or water is a small fraction of their total intake.

Magness expects that continued DU testing will have no significant adverse effects on wildlife found at APG, YPG and JPG.

7.3 U.S. Test Sites

The Army has conducted most of its DU weapons development and testing at three U.S. sites: APG, JPG and YPG. It has mostly used APG to develop DU munitions and armor. JPG and YPG have primarily been used to test fire DU munitions for acceptance testing of production munitions.

Several recent studies (Ebinger et al., 1990; Ebinger, 1992a, 1992b, 1993a, 1993b) of the environmental fate and effects of DU at these sites have been conducted for the Army. These studies provide a summary of the current understanding of the behavior of DU in three distinctly different environments.

Ongoing Army activities can expose military personnel, the public, and the environment to DU. Figures 7-3, 7-4 and 7-5 illustrate potential pathways that may lead to human exposure to DU, including aquatic pathways at APG and JPG and terrestrial pathways at APG, JPG and YPG. Both APG and JPG have wet climates and dense deciduous vegetation. The aquatic pathway at JPG is strictly freshwater. The APG aquatic pathway is both freshwater and marine. Deer are harvested at both APG and JPG (1,200 and 800 animals per year, respectively). All three locations have active environmental monitoring programs.

Environmental monitoring has not detected DU migration out of impact areas at APG, JPG or YPG, but has measured limited movement within the impact areas. DU was not detected in groundwater samples at APG or JPG. Groundwater was not sampled at YPG because the water table there is approximately 700 feet below the surface.

The presence of DU at firing sites allows researchers to study transport mechanisms for heavy metals because DU can be quantitatively distinguished from natural uranium. Enrichment removes ^{234}U and ^{235}U from uranium, giving DU different isotopic ratios of $^{234}U/^{238}U$ and $^{235}U/^{238}U$. These differences can be measured by inductively coupled plasma and mass spectroscopy (Ebinger et al., 1990). The isotopic ratio of $^{234}U/^{238}U$ for natural uranium, as measured by alpha activity, is 0.97; for DU it is 0.13. The $^{235}U/^{238}U$ alpha activity ratio for natural uranium is 0.047; it is 0.013 in DU.

The value of isotopic ratio data was demonstrated at JPG when groundwater monitoring detected high uranium concentrations. Isotopic measurements suggested that the source was natural uranium, not DU. Abbott et al. (1983) later showed that fertilizer used on surrounding farmland caused the elevated uranium concentrations. Further investigation revealed that Florida phosphate deposits used to produce fertilizer have a high concentration of natural uranium (Eisenbud, 1987).

Studies by LANL (Ebinger et al., 1990) and Battelle PNL found that during soft target testing at APG, DU penetrators oxidized into products that contaminated the soil directly beneath the penetrators (Price, 1991). The DU concentration decreased with depth but remained above background and retained the DU isotopic signature at a depth of 20 cm (Ebinger et al., 1990). The APG results suggest that DU migrated through the soil as soluble uranium, uranium absorbed in water-soluble organic acids, or by particulate transport as the result of erosion in the

woodland environment. Unfortunately, data were not available regarding how long the penetrators were exposed to the soil.

LANL studies at YPG found much less DU in soil samples directly below a corroded penetrator. The DU concentration at 8 cm below the ground surface was below the limits of detection. However, sediment samples in an adjacent drainage channel contained DU. YPG has an arid environment, alkaline soils, and deep groundwater. The lack of deep contamination below the penetrator and the presence of DU in the channel indicate that DU transport was dominated by soil erosion. The contaminated sediment found in the arroyo (drainage channel) was from erosion during storms, not from continuous surface water flow. The sediment-transported DU moved about 50 m from the impact site. The high evaporation rate and tight soil greatly limit infiltration at YPG. Thus, DU is unlikely to contaminate YPG groundwater because vertical DU migration is very small, and the depth to groundwater is great. The differences in DU transport at APG and YPG clearly illustrate the importance of soil and climate in the transport and fate of uranium (Ebinger et al., 1990).

The variations in soil contamination observed at APG and YPG are related to the environment (soil type, moisture, temperature, etc.) and the manner in which the penetrators impacted. The studies above were not designed to define the chemical and physical mechanism of DU transport; they provide preliminary data on the migration of DU in environmental media (air, water, soil, groundwater, and ecosystem).

Figure 7-3. Terrestrial Pathway at APG and JPG

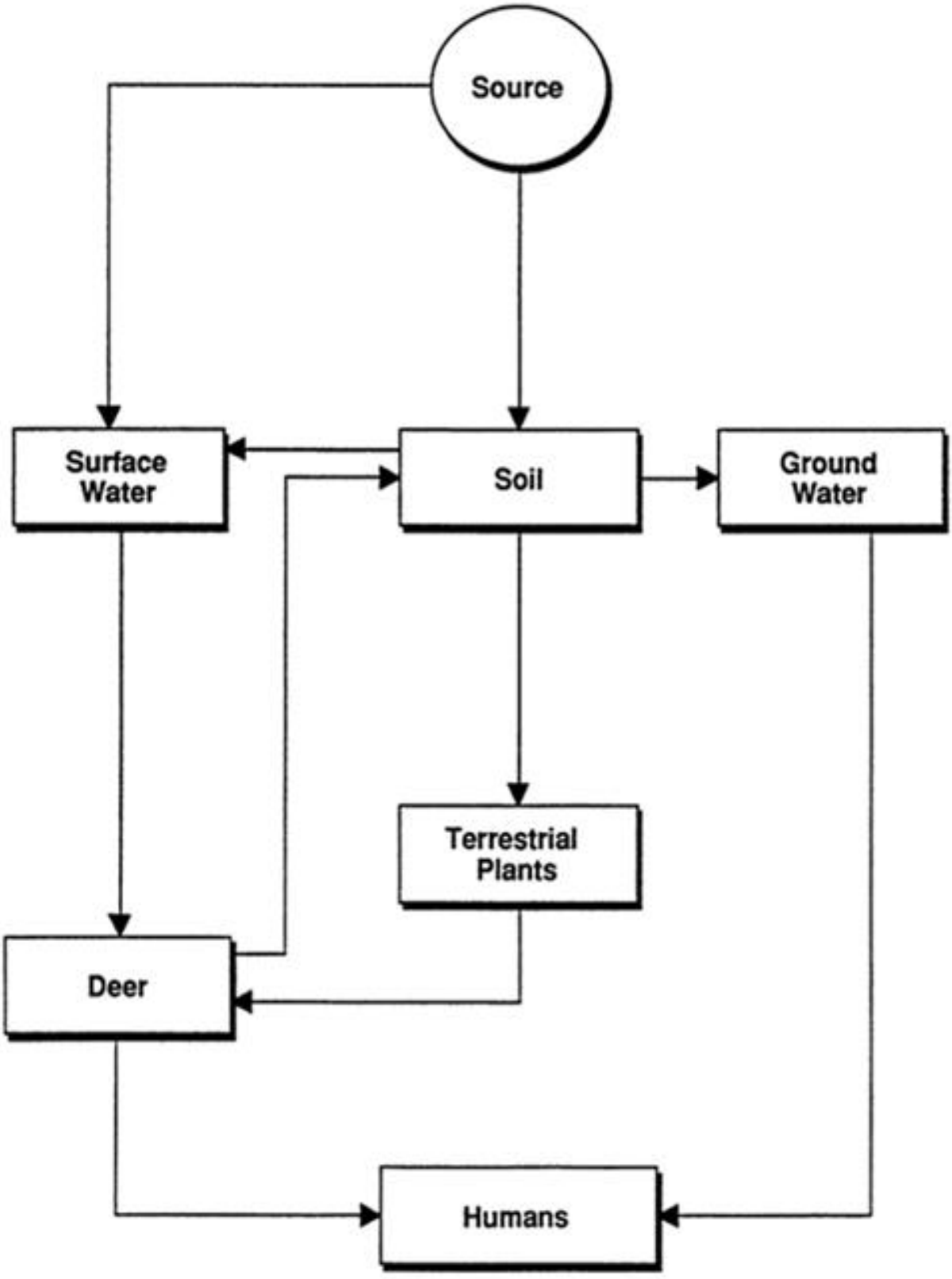


Figure 7-4. Aquatic Pathway at APG

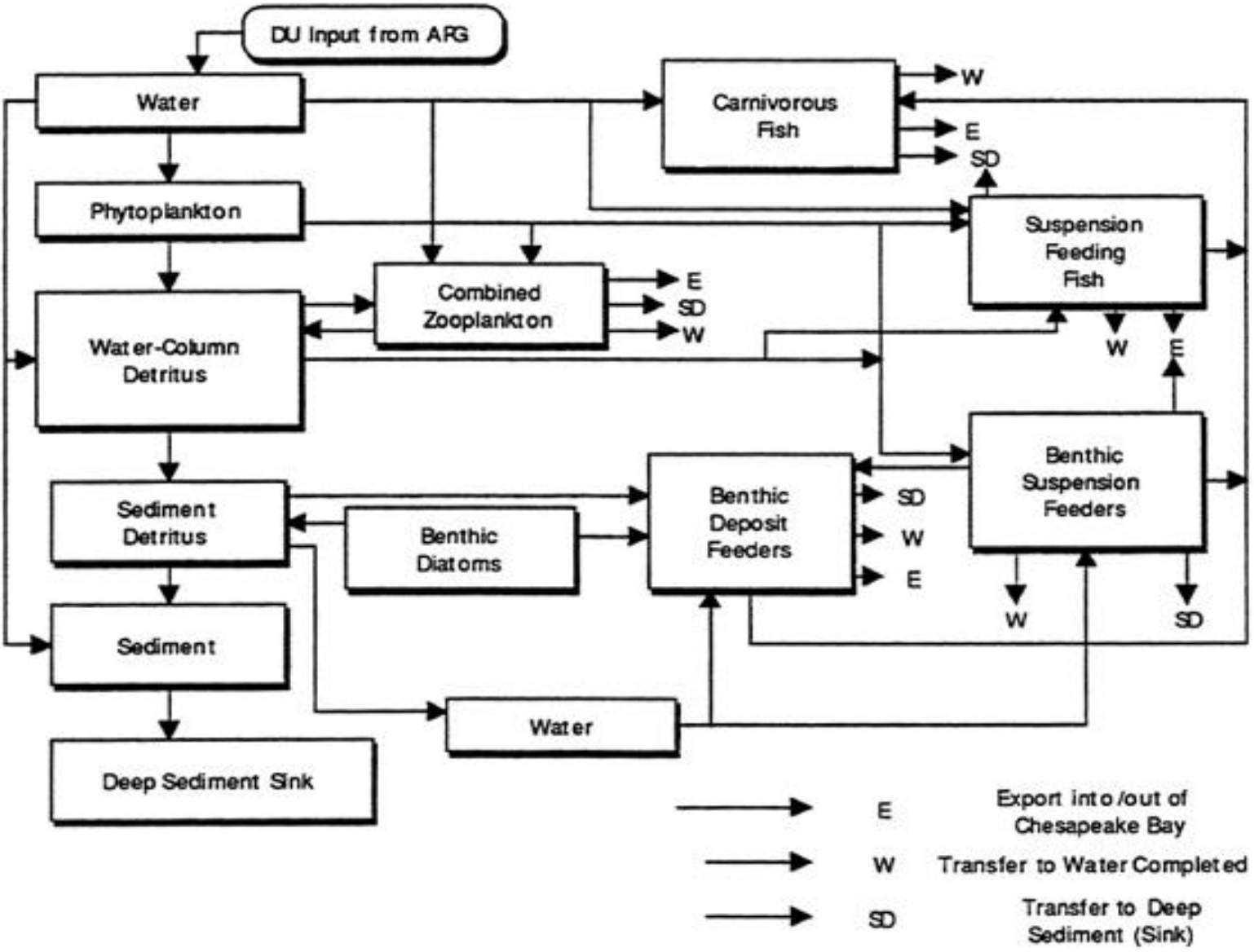
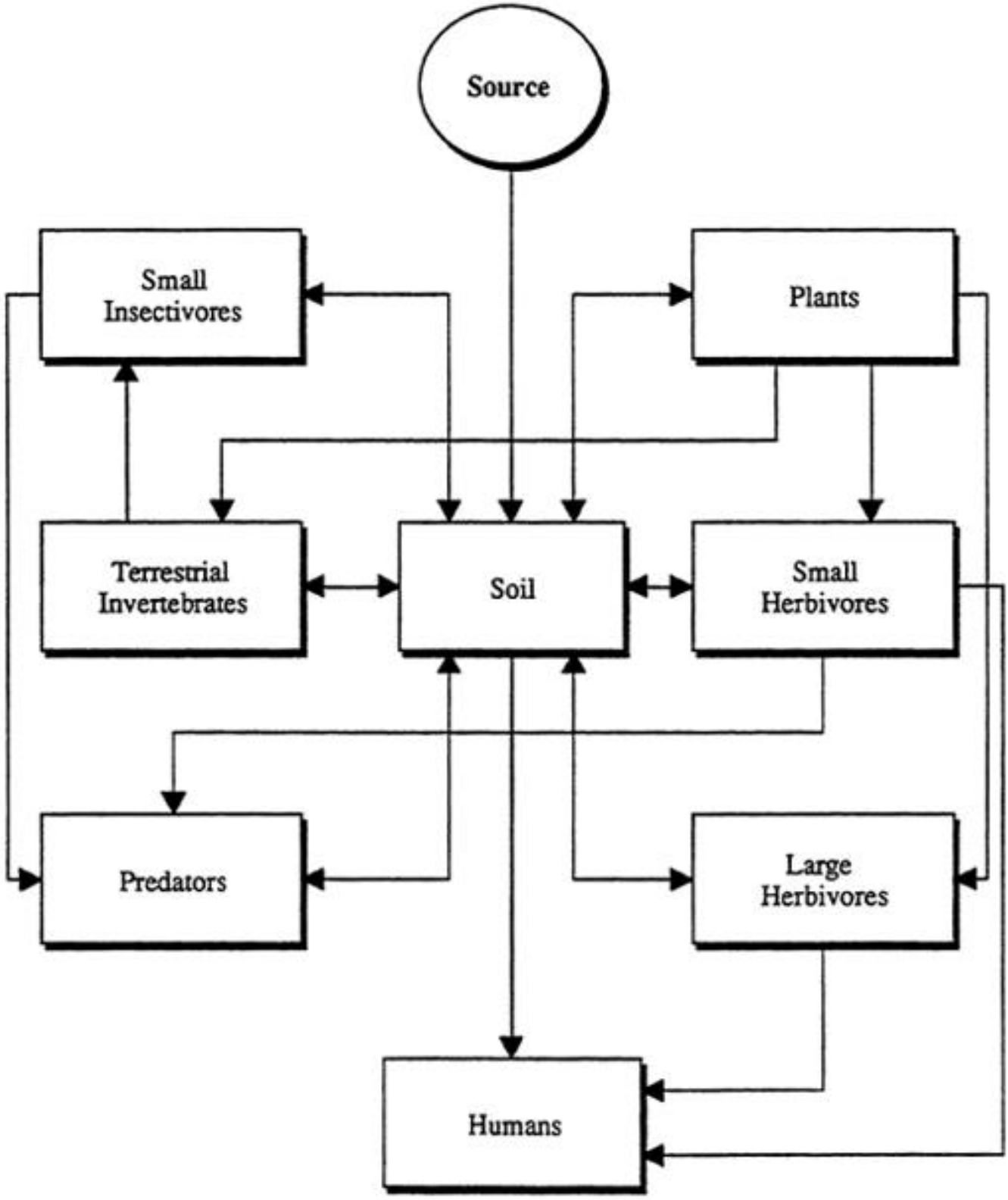


Figure 7-5. Terrestrial Pathway at YPG



PNL's analysis of soil and vegetation samples from YPG found DU in the soil where penetrators first hit the ground or "skip" on or through the soil and in the areas where they ultimately came to rest. Levels of soil contamination were higher in the "skip" areas. Small fragments and particles of DU were visible in the skip areas, indicating that abrasion caused the contamination. Preliminary evidence indicates that vegetation contamination occurred near the skip areas; however, the lack of root contamination implies that the vegetation received a surface coating from the airborne transport of DU rather than from soil uptake (Ebinger et al., 1990). Further studies of the plant contamination would be required to verify this hypothesis.

Where the penetrators landed, soil contamination levels were lower, but the total mass of DU was higher. In this region of the range, large pieces of spent penetrators account for most of the mass. This contributes to a high level of contamination under or near the spent penetrators with essentially no contamination elsewhere.

7.4 Southwest Asia Battlefields

The Army has not conducted environmental sampling and analysis for DU in Southwest Asia, but DU transport and migration should be similar to that found at YPG. However, these speculations cannot be considered definitive without field data.

7.5 DU Contamination

Sites contaminated with DU may need to be cleaned up to reduce health and environmental risks. DU remediation technologies are not well developed; however, many mature technologies from the mining community and

processes used for remediation of other heavy metals may be appropriate for DU remediation. In addition, catch boxes concentrate spent penetrators in one location, rather than allowing them to scatter across many thousands of acres of test range. The development and implementation of catch boxes will greatly reduce the long-term cost of remedial actions at locations where they are used.

7.5.1 Remediation Standards

Remediation of sites contaminated with DU concerns three issues: the degree and type of contamination, the appropriate cleanup technology, and the method of waste disposal. Site remediation typically focuses on the level of DU in the soil. The current standard for soil remediation is 35 pCi/g of soil averaged over any 100 m^2 area, or 100 pCi/g of soil for any 1 m^2 area (58 FR 16268). These criteria are designed so that people on a site will not receive more than 1 mrad/yr of radiation to the lungs from inhalation or 3 mrad/yr to the skeletal system from all routes of exposure.

NRC closure criteria limit the levels of removable and fixed surface uranium (including naturally occurring uranium, DU and their associated decay products). Fixed surface contamination levels cannot exceed an average of 5,000 alpha disintegrations per minute per 100 cm^2 (dpm alpha/100 cm^2), with a maximum of 15,000 dpm alpha/10 cm^2 within a 100 cm^2 area. Removable contamination is limited to a maximum of 1,000 dpm alpha/100 cm^2 (NRC, 1974).

Because some species of uranium are soluble, groundwater contamination is also regulated. While there is no current drinking water standard for uranium under the Safe Drinking Water Act, there is a standard of 15 picocurie/liter (pCi/L) for gross alpha radiation. This criterion is often applied to groundwater for site remediation standards. The EPA recently proposed new

standards for radionuclides in drinking water, including a standard of 20 µg/L for uranium (56 FR 33050). These standards will appear as 40 CFR 141.15. Once the standard for uranium takes affect, states will probably incorporate it in their groundwater quality regulations.

Finally, an evaluation of remediation alternatives must consider standards for disposal of material generated during remediation. Remediation of firing sites will generate soils and sludges contaminated with DU. A study of remediation options for the Naval Weapons Center (NWC) in China Lake, Calif., concluded that, based on its origin, DU is a low-level radioactive waste and, therefore, must be disposed in a licensed repository (Parkhurst et al., 1992). APG has remediated several sites in recent years. All the remediation residuals at APG have been treated as low specific activity radioactive wastes requiring disposal at a licensed low-level waste (LLW) repository.

7.5.2 Battlefield Remediation

No international law, treaty, regulation, or custom requires the United States to remediate the Persian Gulf War battlefields. Before a decision to remediate a battlefield or range could be made, a comprehensive radiological survey and risk assessment should be conducted. A complication of such a survey is determining the location of significant DU contamination. The most significant single action to mitigate Persian Gulf War battlefield contamination is the management of DU-struck Iraqi vehicles to minimize losses of DU particles contained in those vehicles. Beyond that, if soil concentrations could be determined, environmental transport models could be developed to predict the fate and effect of DU in the environment. These data would provide the foundation for risk assessment.

Field data can verify the accuracy and sensitivity of the environmental transport and risk models. The Army can use these models to estimate the risk for various remediation

alternatives, including taking no further action. Model developers need a broad data array to substantiate projections made by the transport and risk models. Therefore, it may be advisable to institute a sampling program at a highly contaminated location, such as the Tomsk, Russia, waste-tank explosion site, to provide an analog for environmental transport of DU. Environmental transport of any type of uranium is a function of its chemical, not its radiological characteristics. The high concentration of uranium oxides in the soil at sites such as Tomsk would allow modelers to gather accurate migration data at a minimum cost. These data would provide the foundation for a technically defensible environmental transport model to estimate the environmental risks of DU on the battlefield and test ranges.

These validated models would allow the Army to make more informed decisions about DU remediation alternatives.

7.5.3 Remediation Technologies

Remediation technologies for sites contaminated with DU are likely to use one or more of the following technologies: excavation and earth moving, physical separation methods, chemical separation processes, and in-place stabilization. Because each site has a unique environment, one must assess the damage that remediation could cause before selecting a remediation technology. This assessment may indicate that it is better to stabilize the contaminant in place. Battelle PNL recently evaluated potential cleanup strategies for use at firing sites contaminated with DU in the arid environment of NWC using the TRUClean™ process (Parkhurst et al., 1992). (No one has much experience remediating DU-contaminated sites in wetter environments.)

Unless in-place stabilization is used, remediation requires excavation. This may range from complete

excavation and secure disposal of all contaminated soil in a low-level waste repository, to excavation treatment to remove DU and re-emplacement of the soil. The principal hazards associated with excavating DU-contaminated soils are the mechanical hazards associated with any large earth-moving project and the toxicological hazards from uranium. If the site also is contaminated with high explosives (HE), then the risk from unexploded ordnance will dominate site remediation management.

When DU-contaminated soils are remediated, the first step is to recover spent penetrators and large fragments. Depending on soil characteristics, this may be done by size classification using a screening device, or it may require hand sorting. Simple screening has been shown to remove up to 50 percent of DU fragments from soil (Parkhurst et al., 1992). Hand sorting requires more personnel protection because it exposes workers to DU metal fragments, respirable DU and DU oxide particles.

A number of commercial processes have been proposed to remediate contaminated soil, including a process designed by TMA/Eberline to clean up Johnston Atoll, TRUClean™, the Chemrad Process, ACT*DE*CON, B&W-NESI Soil Washing, the Mobile Soil Washing System, Frantz Magnetic Barrier Technology and NRT Soil Washing/Chemical Extraction. Some of these processes have been used for remediation; however, all of these technologies are still under development as uranium remediation systems.

Johnston Atoll Plutonium Cleanup

Nuclear weapons tests in the 1960s contaminated the soil of Johnston Atoll, a Pacific island southwest of Hawaii, with plutonium (Pu)-239 and americium(Am)-241 particles. TMA/Eberline was contracted to modify and improve a prior contractor's soil cleanup demonstration plant at the atoll. The modified Johnston Atoll Pu Cleanup Plant is an assembly of standard sand and gravel handling equipment

with advanced instrumentation for monitoring radiation. This plant was designed to process 1,000 yd^3 of soil each week. It uses an array of sensitive radiation detectors and software designed by Eberline Instrument Corporation. The software controls the Segmented Gate System, which diverts contaminated material from soil as it moves along conveyor belts beneath an array of 15 overlapping sodium iodide detectors. Each detector reports to a microprocessor/ computer. The computer diverts contaminated material through segmented gates and logs the radioactivity of both contaminated soil and clean soil. It automatically diverts clean soil in one direction and contaminated soil in another. A metal drum collects hot particles, and a supplemental soil-washing process removes dispersed contamination. Washed soil then passes beneath a second array of radiation detectors to verify that release criteria have been met. The system is processing approximately 100,000 yd^3 of coral soil matrix containing low and intermediate levels of contamination.

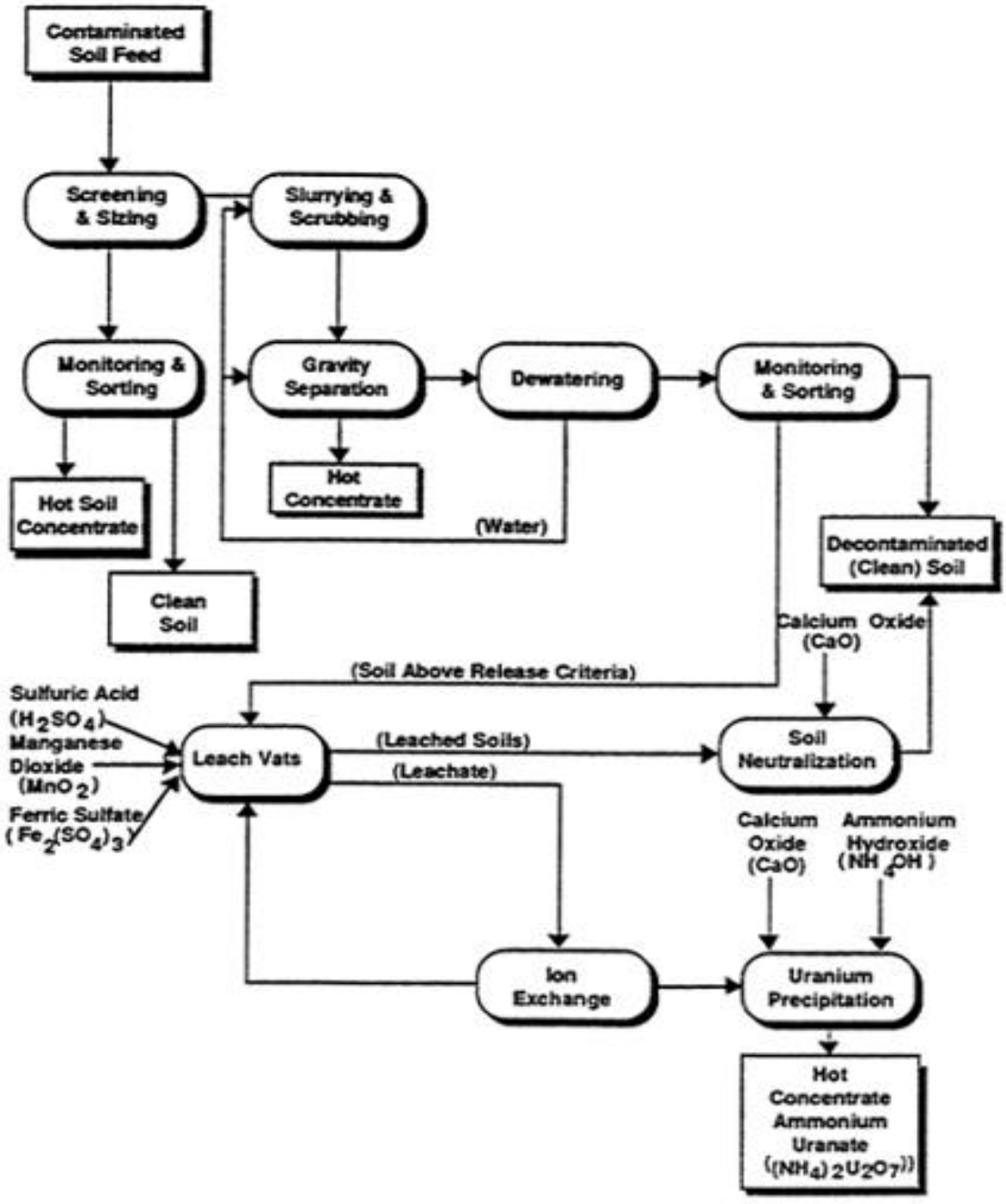
TRUClean™

Figure 7-6 presents a diagram of the TRUClean™ process under continuing development by Lockheed Environmental Systems and Technologies. The process has adapted ore milling technology from the gold and lead mining industries to recover DU from contaminated soil. It uses vibrating screens, mineral jigs and spiral classifiers to separate DU metal from soil slurries (Hall, 1993b). Gravimetric settling separates the very dense uranium metal from soil and water slurries. An oxidant and a strong acid or base are added to oxidize uranium to the U(VI) soluble oxidation state. The dissolved U(VI) is recovered by ion exchange and discarded as low-level radioactive waste. The decontaminated soil is then dewatered and assayed for residual DU.

This technology produces a slurry of decontaminated soil that has been leached with a strong oxidizing agent in a

concentrated acid or base solution. This process may release other heavy metals from the soil. The concentration of other heavy metals could create problems in disposing of the decontaminated soil and/or the leachate. Furthermore, dewatering leached clays is difficult because they are hydroscopic. Leached clays are often referred to in the mining industry as "slimes" because of their poor dewatering characteristics (Thomson, 1993).

Figure 7-6. DU TRUClean™ Process



Gravimetric settling efficiently removes DU metal particulates larger than about 0.1 mm in diameter. It is not likely to remove uranium oxides. If gravimetric methods do not sufficiently decontaminate the soil, the TRUClean process can leach finely dispersed uranium from the soil with an optional chemical separation.

Pilot scale tests of TRUClean on DU-contaminated soil at NWC demonstrated reductions in radioactivity ranging from 85 percent to more than 99 percent. Pilot scale tests at Johnston Atoll reduced the Pu concentration in soil from between 65 pCi/g and 100 pCi/g or higher, to less than 10 pCi/g. The waste residuals after treatment were less than 1 percent (at NWC) and 2 percent (at Johnston Atoll) of the original contaminated soil volume (Parkhurst et al., 1992).

Chemrad Process

A process marketed by Chemrad Technologies, Inc., Louisville, Ky., is much earlier in development. (Marshall, 1993; Bagniefski, 1993). The process is proprietary, so few process details can be disclosed. However, according to Chemrad, the process prepares an acidic slurry of the contaminated soil, then leaches it with an undisclosed lixiviant to remove DU. Chemrad predicts volume reductions in excess of 95 percent based on laboratory studies, and it reports residual DU concentrations in soil of less than 10 pCi/g. After processing, all soils are decontaminated and can be returned to the site. The company has a contract to demonstrate this process on a munitions catch box at the New Mexico Institute of Technology's Energetic Material Research and Technology Center near Socorro, New Mexico. The demonstration began in early 1994, treating approximately 200,000 ft^3 of contaminated soil at 125 ft^3/hr. Chemrad estimated the cleanup time at 13 weeks. The projected cost is less than \$35/ft^3, which may be cheaper than commercial disposal of DU-contaminated soil. The Envirocare contaminated soil

disposal facility in Utah charges $21/ft^3 to $33/ft^3 (Rice, 1993). This Envirocare cost does not include excavation, field sampling and analysis, transportation, engineering, and associated occupational and environmental safety and health costs. As of July 1994, data from the demonstration project were not available.

ACT*DE*CON

The ACT*DE*CON process (patent pending), developed by Bradtec-US Inc., has been tested at the bench scale with various soils and contaminants, including uranium, plutonium, americium and lead. This process was scheduled to be used on a pilot scale at two DOE facilities and on a full scale at one DOE facility during late 1994.

ACT*DE*CON combines dissolution with dilute selective solvents, contaminant recovery and solvent regeneration to provide a continuous recirculating treatment of soils to remove strontium, cesium, technetium, radium, actinindes (uranium and transuranics), barium and lead. The process dissolves and recovers contaminants using countercurrent extraction. The solvent typically used is composed of hydrogen peroxide, sodium carbonate, sodium bicarbonate, 8-hydroxyquinoline and ethylenediamine-tetraacetic acid. Soil is fed to the first extractor where a solvent dissolves the contaminant. The soil is then fed to the second extractor, which mixes partially treated soil and fresh solvent, resulting in further dissolution. The number of extraction stages and the contact time in the extractors is determined by the contamination level, the physical and chemical characteristics of the soil, and the level to which the soil must be treated. After the treated material leaves the final extractor, filters recover the treated soil. The filter cake is flushed with clean water before discharge. The solvent (with contaminants) is treated by either selective ion exchange or evaporation. The solvent can then be analyzed and chemically adjusted before recycling.

B&W-Nuclear Environment Services Soil Washing

B&W-NESI developed a soil-washing system for cleaning approximately 500,000 ft^3 of uranium-contaminated soil from the Apollo Facility 35 miles northeast of Pittsburgh. Soil contamination ranged from zero to 2,000 pCi/g. B&W-NESI treated approximately 1,000 pounds (lbs) of contaminated soil with a bench-scale model of this technology.

Mobile Soil Washing System

The Westinghouse Scientific Ecology Group, Inc., developed the Mobile Soil Washing System technology to separate organics, polychlorinated biphenyls (PCBs), heavy metals and radioactive contaminants from soil. This system screens soil to remove large rocks and debris, then processes the soil in a rotating drum or vibrating screen to sort and prewash it. Large (>2 mm) pieces of soil are washed with leach solution, rinsed with water, monitored and returned to the site. The remaining contaminated soil is processed using equipment from the mining industry. Soils are wetted with the leach solution and the fines are separated. The washed soils are rinsed, monitored, and returned to the site. The fines and wash water go to the precipitation tank. Contaminants are chemically precipitated. The clean leachate is then further treated and sent to the leachate makeup tanks. The highly contaminated precipitate is placed in containers for disposal.

Frantz Magnetic Barrier Technology

The S.G. Frantz Magnetic Barrier Technology separates and concentrates particles according to magnetic susceptibility. It uses a magnetic energy gradient to deflect particles of selected susceptibility from the paths they would normally follow. Most soils are diamagnetic and most radioactive substances are paramagnetic. By using the concentration of diamagnetic compounds of soils, the Frantz

Magnetic Barrier Technology can separate grains that are nonmagnetic by stains of inclusions of radioactive substances. It can process solids from about 2 mm to a few micrometers in size. Pretreatment by sizing, drying and reducing electrostatic charges improves separation.

NRT Soil Washing/Chemical Extraction

Nuclear Remediation Technologies developed a soil-washing/chemical-extraction technology to remove radioactive contamination. NRT performed bench-scale tests of its centrifugal-concentration/soil-washing process on DU-contaminated soils from a firing range owned by Olin Ordinance. The tested soil contained metallic DU particles (4 x 325 mesh) as well as fused silica particles containing U_3O_8. This process reduced the soil radioactivity by approximately 90 percent from 150 pCi/g to approximately 15 pCi/g.

7.5.4 Army Evaluation of Remediation Technologies

The Army needs to evaluate the effectiveness and cost of remediation technologies. It should also identify research and development requirements for new and improved technologies. The Army needs a strategy to address its long-term liabilities from DU contamination of test ranges and perhaps battlefields. This may require examining historical information on the early research and testing of DU-containing weapons. Finally, the Army needs to adequately fund site investigations, and research into remediation technologies and activities.

7.6 Protecting the Environment from Long-Term Consequences of the Use of DU

This report documents several potential environmental hazards created by using DU. These hazards are *potential* because, as noted throughout this report, gaps exist in the data needed to develop environmental transport and

risk models. To achieve long-term, comprehensive, environmentally astute DU management, the Army needs well-funded, thorough investigations to develop and validate models using diverse field data.

This section outlines candidate Army actions that may be used to improve Army management of DU.

7.6.1 Regulatory Cross Links

The review of DoD and Army documents in Chapter 3 indicates that adequate environmental, system safety, and health hazard assessment policies regulate the acquisition of weapon systems. These policies require that the PM conduct environmental, system safety and health hazards analyses of the impacts of a weapon system from its initial developmental concept until DoD accepts the weapon system as an operational inventory item. The acquisition staff concentrates on the life cycle of a system through its operational use in the field. Acquisition policies, however, do not adequately consider the environmental consequences of system disposal. The regulations do not explicitly require the PM to consider the environmental costs from development through acquisition, use, demilitarization, and disposal.

Chapter 3 also indicates that when a system is obsolete, demilitarization and disposal policies require the Army to consider the environment when determining final disposition. These policies also regulate the transfer of obsolete systems from operational forces to demilitarization and disposal personnel. In addition, the PM must develop a demilitarization and disposal plan before producing ammunition and releasing it to operational forces. This study found several such plans for demilitarization or disposal of DU ammunition. However, acquisition regulations do not explicitly require a disposal plan and R&D and Demilitarization and Disposal regulations do not

explicitly refer to environmental regulations. Thus, the regulatory requirements do not appear to be cross-referenced.

If the regulations were cross-referenced, the relationship between acquisition and disposal of weapon systems regarding environmental requirements would be much clearer. Furthermore, demilitarization and disposal staff members would know what to expect when they receive an obsolete system.

The existence of environmental and safety policies and procedures does not guarantee that the Army adequately analyzes environmental, system safety and health hazards when acquiring and disposing of weapon systems. Acquisition and disposal PMs must also receive adequate environmental training. The Army needs to audit its environmental training programs for these managers.

Besides the environmental, safety and health hazard policies that exist in acquisition, demilitarization and disposal regulations, AR 200-2, *Environmental Effects of Army Actions*, provides detailed environmental policies. AR 200-2 describes each step of the environmental analysis [specified by the National Environmental Policy Act (NEPA)] that a PM must consider for every new system. It also provides a way for the Army to examine any new environmental issues—the Life-Cycle Environmental Document (LCED). Given that some DU work began before NEPA, LCED offers the best available means to reexamine the environmental consequences of DU systems. In view of the current concerns relating to DU, an Army review of all of these documents to develop a baseline of knowledge on the environmental documentation for all DU systems could prove useful. This overview might lead to an Army decision to prepare a new programmatic LCED, or it might provide sufficient data to avoid this costly and time-consuming exercise.

The DoD 5000 series regulates all weapons development. It stipulates that a PM must consider the total cost of a system, including development, acquisition, support and disposal. This total cost is called the Life-Cycle Cost (LCC). LCC is an integral part of decisions in several areas, such as the Program Office Life-Cycle Estimate, Independent Cost Estimates, and selection of materials (including hazardous and radioactive materials). However, the 5000 series often uses the term LCC to refer only to the cost of development, testing, production and support. For example, DODI 5000.2, Part 4, Section E, states that LCC "reflects the cumulative costs of developing, procuring, operating, and supporting a system." Disposal is not considered. In addition, formats in DODM 5000.2-M, such as in Part 4, Section C, do not include disposal in the Program Life-Cycle Cost Estimate Summary. The 5000 series does not need major changes; however, some minor changes could significantly affect how the Army accounts for disposal costs. These changes would also help the services focus on the ultimate financial impact over the life cycle of each system.

7.6.2 Federal Acquisition Regulation

The Federal Acquisition Regulation (FAR) does not require contractor proposals for DU weapon system production to include costs for equipment and facility decontamination once manufacturing has concluded. Because a facility can operate for many years, the Army has treated these costs as contingent liabilities and not as allowable costs under FAR. However, because defense funding is shrinking, more facilities are closing, making facility decontamination issues more important. By precluding cleanup costs in weapon systems proposals, FAR creates a subtle disincentive for contractors to maintain clean facilities. This may subsequently lead to disputes between

contractors and the Army over cleanup liability. Therefore, FAR should mandate that all contract bids include cleanup costs.

7.6.3 NEPA Documentation

AR 200-2 requires that the Army follow the NEPA process, which includes preparing appropriate environmental documentation while fielding and deploying weapon systems. As of July 1994, all the environmental assessments that the Army prepared for DU weapon systems have had a *Finding of No Significant Impact* (FNSI).

10 CFR 51.22 (c)(14)(xv) categorically excludes the NRC action of issuing, amending or renewing materials' licenses issued for possessing, manufacturing, shipping, testing, or other use of DU in military munitions from NEPA. It does not relieve licensees of the responsibility for assessing the impact of a DU license on the environment. The regulation states, however, that NRC is not required to comply with NEPA when *granting* the license.

The NRC's categorical exclusion and the Army's environmental assessments consider only peacetime manufacture, storage, transportation, testing, and disposal. Environmental impacts under likely battlefield uses have not been formally assessed. In light of concerns about the long-term environmental effect of using DU, it may be appropriate for the Army to explore the possibility of preparing a comprehensive Programmatic Environmental Impact Statement (PEIS) for DU weapon systems.

7.6.4 Environmental Assessments

According to AR 200-2 and NEPA, the Army has prepared environmental documentation for all its systems containing DU except those developed before NEPA. Section 3.3 identifies 16 such environmental documents. The environmental documentation reviewed during this study showed a steady improvement in the amount of detail and

research in each successive system document. In applications outside the Army, such as construction projects, an EA is site-specific. Within the Army, however, an EA is usually an item-specific document that attempts to cover sites where the item will probably be manufactured, tested, stored, or demilitarized. When the Army prepares a site-specific EA, the document assesses the cumulative impact of many systems. Use of the same term for two entirely different applications may be confusing an could lead to the erroneous conclusion that the appropriate environmental documentation has been prepared.

The Army publishes each EA and a description of its findings in local newspapers serving the installation that prepared it. After publication, the Army establishes a comment period. Picatinny Arsenal, in N.J., prepares EAs for ammunition, while TACOM, in Warren, Mich., prepares EAs for tank armor. However, as discussed in Chapter 3, DU components for Army systems are manufactured, assembled, tested, stored, and disposed at many U.S. sites. The Army does not publish EAs in newspapers serving each site, so communities do not always know they can comment on the documented findings. The Army could resolve this issue by publishing EAs and FNSIs in a national medium and local media in all affected areas.

7.6.5 Programmatic Environmental Impact Statement

Because of controversy about the use of DU in Desert Storm and at DoD test ranges, the Army should consider preparing a DU LCED at a programmatic level. This document could be an umbrella environmental assessment or impact statement covering all aspects of DU use, testing, and disposal in the Army. Future use of DU that might require an EA could be appended to the LCED, reducing the cost of site-specific EAs. Finally, a generic DU LCED could be used to educate the public concerning Army environmental programs to manage DU.

7.6.6 NRC License Management

Various AMC subordinate commands hold 14 NRC licenses for managing DU ammunition and armor. The licenses are site- or mission-specific. This arrangement should accommodate the licensee missions, but the lack of coordination between the license holders has resulted in management problems. These problems have surfaced in instances where DU ammunition has been shipped to locations not authorized to store DU and also in situations where excess DU has not been properly removed from inventory.

A licensee that ships DU is liable for the shipment of radioactive material and must ensure that the recipient is licensed to receive the shipment. AMCCOM and ARDEC hold NRC licenses. AMCCOM's license is restricted to specific, type-classified ammunition, while ARDEC's is limited to use and storage of DU for R&D at Picatinny Arsenal. Item managers at AMCCOM, ARDEC, PM Tank Main Armament Systems (TMAS) and PM Bradley can ship DU ammunition. Unfortunately, ammunition item managers have violated license restrictions by directing ARDEC to ship R&D ammunition to locations not licensed to store or use it.

Ammunition item managers could avoid these violations if AMCCOM's license authorized all DU ammunition, including R&D ammunition. Because licensees can be cited and/or fined for license violations, licensees have established several restrictions to ensure that they can accomplish their missions without being held responsible for personnel actions beyond their control. AMCCOM and ARDEC are apparently reluctant to expand their responsibilities because they do not think their missions require such changes; they think the changes could increase their liability.

NRC limits the amount of DU that Army test centers can possess. Test centers have DU in ammunition awaiting testing and in unrecovered penetrators in impact areas and catch boxes. They also may have radioactive wastes from enclosed firing ranges and armor targets. In addition, because licensed developers do not provide disposition instructions for R&D ammunition that has completed testing, test centers must store this ammunition, which NRC includes in their DU inventories. This storage may prevent test centers from receiving new test material if they are approaching their possession limits. The test centers cannot dispose of the material as radioactive waste because it must first be demilitarized. They cannot ship it to a depot for storage without the item manager's direction. On the surface, this appears to be an AMC management problem, but it actually extends to the Secretariat level because PM Bradley and PM TMAS report to the Assistant Secretary of the Army for Research, Development and Acquisition.

The Army could improve its management of DU by consolidating the 14 current licenses into a single NRC license managed by AMC Headquarters (HQ), the DA, or a centralized DU management and research authority. AMC management would require cooperation by the various PMs. DA management could follow the policies now practiced by the Air Force and Navy; each have consolidated their licenses into a master materials license managed at the department level. A central DU management and research organization could also ensure compliance with Army policies and NRC license requirements.

AMC is currently the principal Army DU management and research authority. Regardless of the licensing structure, systemic issues concerning DU will require substantive AMC involvement.

7.6.7 Catch Boxes

The Army has shown that catch boxes can limit the amount of DU dispersed in the environment. Concentrating

DU within catch boxes reduces the DU available to contaminate ecosystems in impact areas. The expense of periodically remediating and recovering contaminated sand and DU in catch boxes will increase the cost of testing DU penetrators. However, remediating a catch box is more cost-effective than remediating thousands of acres of a range. DU range remediation is an RDT&E cost that is deferred until the range is taken out of service. There is no current plan to escrow these costs or attribute them to development of the weapon systems that generate the contamination. Therefore, because the Army cannot place RDT&E funding in escrow, developers and PMs must address planning and funding for remediation independently of the systems that created the contamination. This discontinuity does not meet the spirit of AR 200-2.

7.6.8 Demilitarization and Recycling

The Army, as reported in Chapter 3, is developing a DU weapon system demilitarization process. This process will develop standard processes for weapons demilitarization that comply with applicable environmental laws and regulations, including waste treatment and disposal criteria. Once complete, the Depot Maintenance Work Requirements (DMWRs) will be revised to reflect the protocols for DU weapons demilitarization.

In addition to programmatic demilitarization planning, the Army has undertaken efforts to recycle DU materials. Recovering and reusing DU may reduce the potential long-term liabilities of disposal. The Army should continue to support these programs.

7.6.9 Disposal

Managers of Army firing sites face many challenges and substantial uncertainties when disposing of DU waste. Table 7-1 summarizes DU waste management actions for APG during 1992.

Because USACSTA and ARL-Aberdeen test fire DU penetrators against conventional and DU armor plate, APG is the biggest generator of non-medical low-level radioactive waste in the Army. These tests have generated waste faster than funds or landfill space have become available, forcing APG to maintain a backlog of DU waste. While these problems do not now prevent firing sites from testing DU projectiles, these problems could in the future if the Army does not resolve three problems:

- NRC counts stored DU wastes (including unspent R&D ammunition that has completed testing) against the maximum amount of radioactive material a testing center can possess.

- DU storage, recycling and disposal capacities are inadequate at existing facilities.

- Funding of both current and projected waste disposal requirements is inadequate.

Table 7-1. 1992 DU Disposal and Recycling Operations at Aberdeen Proving Ground

Waste Form	Disposal Option	Waste Generated	Amount Disposed	FY93 Inventory
Armor Plate Contaminated with DU	Recycling by SEG †	600 tons/yr	3,300 tons	450 tons
Combustible/Compactable*	Incineration by SEG	13,100 ft^3/yr	69,900 ft^3 689 tons	7,500 ft^3
Classified Waste *	Disposal at a DOE Facility	10,000 ft^3/yr	21,000 ft^3 1,040 tons	1,500 ft^3
Contaminated Soil*	Disposal at Envirocare Facility, Utah	4,800 ft^3/yr 300 tons/yr	0	12,000 ft^3

Source: Cardenuto, 1993

* Values shown correspond to the total amount of waste material, not just to DU.

† SEG = Scientific Ecology Group

The lack of funding for current and projected waste disposal requirements is manifested in two ways. First, AMC delays sending funding to waste management programs. For example, AMCCOM, the Army unit that manages radioactive waste, did not receive funds budgeted for programs at APG during FY92 until September 1992. As of July 1, 1993, AMCCOM had not received funds for APG to initiate FY93 programs. Budgets were revised several times during each fiscal year (FY) before the money was finally received. It is difficult to manage a system when neither the amount of money nor its arrival within the FY are known in advance.

Second, budgeted funds are not adequate for current waste disposal and recycling mandates. For example, in FY92, YPG requested funds for disposal of 40,000 ft^3 of DU-contaminated soil, but AMC denied the request because of a lack of funds. APG has approximately 12,000 ft^3 of contaminated soil in storage that is ready for disposal. Moreover, it is estimated that another 20,000 ft^3 of contaminated soil must be cleaned up at APG in the future. The Appalachian Low-Level Waste Compact, which includes Maryland, has approved disposal of this material as a low-specific activity waste at Envirocare of Utah, but APG has no funds budgeted for this disposal. The current estimate for disposal of the existing stored soils at APG is $3 million. Costs for loading, packaging and transporting this material to the Utah facility are estimated at $120,000.

The inability to dispose of accumulated DU and contaminated soil could limit activities at existing firing sites. As previously explained, each site operates under a license, issued by NRC or an "agreement state," that specifies the total amount of radioactive material the facility may have in its inventory. Accumulated waste material and stored R&D ammunition are subject to the provisions of these licenses, such that a large inventory of waste may limit the ability of a facility to receive additional DU material for testing. At the end of FY91, the total amount of DU waste material generated at

USACSTA was estimated to be 100,000 kilogram (kg), most as metal from recovered and unrecovered penetrators and DU armor. This material counts against the maximum permitted mass of DU under provisions of USACSTA's license. Any interruption in recycling and disposal activities resulting in the accumulation of additional DU could force USACSTA to stop testing unless NRC approves an increase in the maximum permitted mass.

In addition to the problem of funding inadequacies for waste disposal, there is legitimate concern that LLW disposal sites will not be available. The Low-Level Radioactive Waste Policy Act required all states to take responsibility for disposal of their LLW. To motivate states to take this responsibility, the act allowed commercial repositories to refuse waste shipments from states that do not have their disposal facilities or did not enter compacts by December 31, 1992, with states that have disposal facilities. Only two commercial sites now receive low-level waste: Hanford, Wash., and Envirocare of Utah. Barnwell, S.C., stopped accepting Army LLW in July 1994. Until their compact sites are operating, Army facilities outside compact states served by the commercial LLW disposal facilities (YPG, APG, and JPG) may encounter difficulties disposing of DU wastes. For example, the Appalachian Compact, which includes Maryland, is not scheduled to open until 1999 (Cardenuto, 1993b). This aspect of the act may seriously affect Army management of waste materials containing DU because the Army has installations across the country and no reasonable way to facilitate formation and management of regional LLW compacts.

Under the Appalachian Compact, no member state will be allowed to dispose of more than 25 percent (averaged over 3 consecutive years) of the amount of waste generated by Pennsylvania, the state that will host the final repository. APG was the major generator of LLW in Maryland from 1987 to 1989, disposing of 41,644 ft^3, which represented 21.2 percent, 61.9 percent and 46.3 percent of the total waste the state

disposed in each of those years, respectively. Under compact provisions, the waste disposed by Maryland from 1987-1989 had a 3-year average of 22.7 percent of the total waste disposed by Pennsylvania, thereby approaching the 25 percent allowed. If Maryland were to exceed its allowance in the compact, it is not clear how APG would be treated in terms of its waste allocation.

This combination of factors may constrain APG's ability to dispose of waste, thereby, increasing its DU inventory. This could, in turn, limit its testing. If the diversity of DU-related activities across the Army is viewed in the national context, the current state-compact approach to managing LLW may adversely affect the national interest. The Army should encourage Congress to consider a system that evaluates the relative value added in each phase of development, testing and fielding a DU weapon system and allocates a proportional share of the waste generated to all states that benefit from the process.

To preclude future disposal and cross-contamination problems, the Army needs to provide a means to ensure the timely disposal of waste residuals from DU firing ranges. Improved recovery and recycling programs are part of the answer to this problem. The Army should continue to investigate ways to improve the technology for containing and recovering DU from firing ranges, as well as ways to encourage development of markets for recycled DU. The Army should also recognize that DU testing will always produce waste. The Army should continue to actively participate in developing disposal options for LLW, including volume reduction, waste minimization, waste-form modification and new disposal facilities.

7.7 Summary

Uranium, regardless of the isotopic mix (DU, enriched, naturally occurring, etc.), is identical in matters of chemical

toxicity and environmental mobility. DU can be moved through the environment by water, wind and biological transport. Army studies of the dispersal of DU particles after a penetrator hits a hard target show that the extreme density of the particles limits most airborne transport. DU's mobility during aqueous transport is determined almost exclusively by its solubility, which in turn is determined by its oxidation state. Minerals in the soil where a DU penetrator lands affect how fast the penetrator will corrode and become soluble. Research has shown that DU is not effectively transported in the food chain, partly because organisms low in the food chain quickly excrete most soluble uranium species.

Plants growing in soil contaminated with DU typically concentrate DU in their root systems. Some plants appear to have a mechanism to limit their DU intake. Because DU has a low specific activity and most animals in the natural environment do not live very long, the principle hazard associated with animals ingesting uranium is toxicity, not radioactivity.

Studies at YPG found DU in two locations on firing ranges: in the skip areas, where penetrators passed through the soil, and in the areas where they landed. Contamination was higher in the skip areas but a greater mass of DU was found where the penetrators landed. Studies at APG, JPG and YPG have shown that although DU has not migrated out of firing areas, it has moved some within these areas. DU was not detectable in groundwater samples at APG or JPG. Groundwater was not tested at YPG because the water table there is about 700 feet below ground. DU contaminated more soil directly beneath corroded penetrators in the wet, deciduous climate of APG than in the arid climate of YPG. However, DU contaminated an arroyo near an impact area at YPG. The DU moved less than 50 m from the impact area and is unlikely to contaminate the very deep water table at YPG.

Although studies have not been done in Southwest Asia, DU transport and migration there would probably be similar to that found at YPG.

Site remediation typically focuses on the level of DU in the soil. Although water quality standards currently do not regulate uranium in drinking water, revised drinking water regulations will probably specify a limit for uranium of 20 µg/L. Evaluation of remediation alternatives must also consider standards for disposal of material generated during remediation.

No international law, treaty, regulation, or custom requires the U.S. to remediate Operation Desert Shield/Desert Storm battlefields. Before remediation could occur, a comprehensive radiological survey and risk assessment should be conducted, but this would not be possible until scientists have developed an environmental transport model that predicts the movement and transformations of DU in the environment.

To develop an environmental transport model, researchers need to study a site with a high concentration of radioactive contamination, such as the Russian waste-tank explosion site at Tomsk. The high concentration of actinides in the soil there should provide the broad data array necessary for developing an accurate model. Once a model is developed, it can be used in surveying any DU contamination site, including those in the U.S.

The Army needs to develop a strategy to address the long-term liabilities of DU contamination at test sites and perhaps at battlefields.

Numerous commercial remediation processes are available for contaminated sites. Almost all of these processes use one or more of the following technologies: excavation and earth moving, physical separation methods, chemical

separation processes, and in-place stabilization. The Army needs to evaluate the effectiveness and cost of existing remediation technologies and to continue to seek new and improved technologies.

The Army should consider the following candidate actions that may be used to improve Army management of DU. It should consider:

- Consolidating the 14 current NRC licenses under the management of a centralized DU research and management authority.

- Providing adequate cross-references in acquisition, demilitarization and disposal regulations.

- Preparing a DU Programmatic Environmental Impact Statement.

- Publishing Environmental Assessments and FNSIs in a national medium and local media in all affected areas.

- Using catch boxes for all DU munitions testing, and ensuring that developers and PMs make provisions for eventually remediating the contaminated sand the catch boxes contain.

- Expanding efforts to recycle DU.

- Addressing the problems of LLW disposal.

In addition, the FAR should mandate that all contract bids for DU weapon system production include cleanup costs.

8 FINDINGS AND CONCLUSIONS

"The earth and its resources belong of right to its people."

— Gifford Pinchot

This report considered the health and environmental effects of the use of DU within the U.S. Army. Overall, the Army has done an excellent job of producing and fielding weapon systems that contain DU. The data gathered during this study clearly indicate that, from the onset of DU weapons research, the Department of the Army recognized its responsibility to seek ways to reduce risks. To this end, the Army complies with established statutes, regulations, and procedures.

Before the Army developed and fielded DU munitions and armor, it conducted extensive tests and repeated reviews to ensure that the items would be combat-effective and safe to use. It also continuously considered health and environmental challenges during development, testing and fielding of weapon systems containing DU.

Moreover, a commitment is embedded across DU weapon programs to minimize exposure of Army personnel, the public, and the environment to the potential hazards of DU. The Army's military and civilian employees manage chemical and radiological environmental hazards. These dedicated professionals daily demonstrate the Army's commitment to meeting DU environmental, safety and health criteria. Furthermore, as a result of discussions during this investigation, the Army has initiated and

expanded several efforts to improve the management of DU health and environmental issues.

Nevertheless, AEPI identified several DU-related areas that require further attention. A few of these areas are potential weaknesses in Army programs, but most are ways to enhance current practices and procedures. The findings and conclusions identified herein are not intended to criticize those who have been responsible for managing DU. Instead, the options presented describe efforts to attain an even higher level of health and environmental security. AEPI believes these candidate options will further enhance a DU program that is already well-reasoned.

The Institute's findings presented below address the four areas of concern that Congress expressed in Senate Appropriations Committee Report Number 102-408. The findings are followed by major conclusions that address DU environmental safety and health issues.

8.1 Findings

The findings presented below address the four areas of concern that the Office of the Assistant Secretary of the Army (OASA) Installation, Logistics and Environment (IL&E) tasked AEPI to study in response to the Senate Appropriations Committee report:

- A battlefield may be contaminated with many dangerous things. The impact of DU contamination on the battlefield is a new issue and is not well-defined. Relative to many other hazards, such as unexploded ordnance, the hazards from DU contamination are probably small; however, additional environmental modeling and data are needed to support this judgment.

- DU remediation technologies involve one or more of the following processes: excavation and earth moving, physical separation, chemical separation, and in-place stabilization. Very few remediation technologies have actually been used to clean up DU-contaminated sites. The Army continues to identify and evaluate alternative remediation technologies.

- No available technologies can significantly change the inherent chemical and radiological toxicity of DU. These characteristics are fundamental to the element uranium.

- The Army has implemented range management and DU recovery systems and is improving these systems. The Army is also developing models to better describe the environmental fate and effects of DU. DU migration on test ranges in the United States appears to be insignificant because the soil and water conditions on the ranges tend to prevent formation of soluble DU.

8.2 Conclusions

8.2.1 General Conclusions

DU Management Office

The Army or DoD should designate a single office, independent of DU systems development or use, to improve management and control of DU health, environmental, and regulatory issues.

An independent organization overseeing DU use in the Army could improve the coordination between acquisition, use, demilitarization and remediation activities. This DU management office, functioning as the principal expert, could:

- Assure compliance with applicable laws and regulations.

- Consolidate the Army's current 14 Nuclear Regulatory Commission, non-medical DU systems licenses into a single license. This single license would alleviate present monitoring, equipment, and operational inconsistencies.

- Establish a mechanism for scientific peer review of all DU health and environmental testing and research programs.

- Serve as a focal point and repository for all information on the health and environmental effects of DU.

- Design, coordinate, and evaluate health and environmental research programs.

- Assure that weapon testing programs include acquisition of well-reasoned environmental safety and health data.

Revise Army Regulations

The Army should revise its regulations and policy documents to explicitly link the acquisition, use, safety and health, disposal, demilitarization, and environmental management of DU. This could serve as a model for a DoD system.

Current regulations and policy documents adequately express the environmental, system safety and health hazard assessment issues associated with weapon systems during specific phases of their life cycles. However, no explicit cross-references exist between the policies of each regulation. Adequate cross-references would ensure that those responsible for acquiring a system

would be exposed to the environmental regulations and would become familiar with environmental aspects of the ultimate demilitarization and disposal of the system. Specifically, demilitarization and disposal experts would know what to expect when accepting an obsolete system containing DU.

Analyze Life-Cycle Costs

The Army should determine the full life-cycle cost of DU weapon systems. This analysis must take into account not only production costs, but also demilitarization, disposal and recycling costs; facility decontamination costs; test-range remediation costs; and long-term health and environmental costs. Specifically, the Army should:

- Recommend changes to the DODM 5000 series to help the services focus on the ultimate financial impact of DU weapon systems over their life cycles.

- Recommend changes to the FAR to require that all contracts for weapon systems containing DU include the full cost of environmental control and cleanup of equipment and facilities contaminated during execution of the contract.

- Require that acquisition methodologies for alternative materials to replace DU include detailed analyses of their life-cycle environmental and health risks. These materials should be evaluated on the basis of unbiased estimates of the health and environmental risks (chemical and radioactive) and full life-cycle costs.

- Require that PMs use independent, expert peer review of proposals, data and reports on the health and environmental effects of DU systems. This would make it easier to better estimate full life-cycle costs for weapon systems.

- Modify laws and regulations that preclude escrow of funds to pay for future test range remediation costs. Currently, weapon system RDT&E projects cannot be charged for environmental remediation costs accrued by developers and PMs. This artifact obviates the life-cycle environmental management mandates in AR 200-2.

Environmental Assessment

An Environmental Assessment is normally used to assess the incremental impact of systems at a specific site; however, within the DoD's acquisition process, an EA can also be item-specific (pertaining to a specific weapon system). Use of the same term for two entirely different types of assessments could lead to an inappropriate conclusion that the requisite environmental documentation has been prepared.

The Army does not publish EAs in media serving each site. This often leads to a perception of avoidance and deception in local communities. The Army could resolve this by aggressively seeking local comment on EA documents at all levels through local and national media.

8.2.2 Test Ranges and Battlefields

Expand Training

The Army should continue to improve training programs for the wide variety of soldiers and support personnel who may come into contact with DU or DU-contaminated equipment. At a minimum, the Army should include armor, infantry, engineer, ordnance, transportation and medical personnel in this training. Specifically:

- Soldiers need additional training on the hazards and management of DU armor and ammunition.

- Soldiers need training on the hazards of DU, on the methods to detect DU, and on the protection and decontamination measures that can be used in the field.

- The Army needs to revise manuals for weapon systems that contain DU components so the documents clearly identify DU components and their potential hazards.

- Managers throughout the Army weapon system community (acquisition, field and demilitarization) need more training on health and environmental issues that may become important over the life cycle of weapon systems containing DU. The Army needs to audit environmental training programs for these managers. Data from this audit would provide a framework to expand or modify training programs to ensure adequate coverage of environmental safety and health issues.

- Medical personnel need to understand the radiological and toxicological properties of DU and the medical procedures required to treat patients with internal DU exposure.

In response to previous documentation on the need for additional training, the Army has begun to develop some of these programs.

Assess Medical Surveillance

The Army Surgeon General evaluates all Army weapon systems to ensure that potential health effects are satisfactorily mitigated before fielding. During combat operations, however, new health-related issues may emerge. For example, before Desert Storm the probability of human survival in a vehicle hit by a DU penetrator was estimated to be quite low; however, the actual survival rate for U.S. soldiers in vehicles that sustained friendly fire

DU strikes was more than 80 percent among Bradley crews and more than 90 percent among Abrams crews.

For this reason, in future conflicts where DU weapons are used by either side, the Army should anticipate managing patients with DU-contaminated wounds. The Army Surgeon General should review its standard field medical procedures to ensure they are adequate to treat DU-contaminated battle wounds. Medical risks from DU to the patient and the health care provider, however, must be kept in perspective when treating trauma wounds.

To manage potential health impacts from the use of DU weapon systems, the Army Surgeon General should:

- Continue to identify veterans who may have been exposed to battlefield DU. Use the resulting data to develop a protocol to assess the extent of their exposure and manage their care.

- Develop a formalized standard procedure to identify and manage DU contamination during medical procedures. Medical personnel should use radiation detection instruments to help locate and remove DU contamination from patients and the treatment facility.

- Train medical personnel to manage DU-related health risks.

- Develop protocols for managing DU fragments, wound decontamination, and inhalation exposure.

- Develop or define procedures to measure the amount of DU internalized.

- Continue evaluating and monitoring veterans wounded by DU fragments.

- Continue to support research to determine the long-term consequences of embedded DU fragments. Continue follow-up efforts if warranted by the data generated from the Desert Storm soldiers currently under treatment or observation.

- Develop models to estimate the radiological and toxicological consequences of DU internalized as a result of inhalation, wound contamination, or embedded fragments.

- Continue to identify Desert Storm personnel who were involved in DU friendly fire incidents but were apparently not injured. This process will aid in documenting exposure levels and will provide valuable data on the inhalation potential of aerosols containing DU.

Assess Exposure Potential

The Army should continue to investigate equipment modifications and procedures that will minimize exposure to the chemical and radiological hazards of DU. Specific projects should include:

- Develop a combat-oriented document, similar to TB 9-1300-278, that would define protective techniques for personnel dealing with vehicles potentially contaminated with DU. The new guidance must consider the trade-off between DU risks and combat risks. This trade-off should be a sliding scale because risk from combat decreases as a damaged vehicle is recovered from the active fire zone and returned to rear areas for maintenance or salvage.

- Develop standardized markings for all weapon systems containing DU. Current markings on Army items containing DU are inconsistent and sometimes misleading. Use of euphemisms, such as “staballoy,” should be eliminated.

• Inhalation presents a pathway for DU internalization for recovery and maintenance personnel who work in and around contaminated vehicles. The Army needs to conduct further experiments and analysis to better define these risks. Data—including particle size, concentration, density, and oxidation state—are required to evaluate resuspension and inhalation potential. These data are also necessary to determine the protective measures that could protect personnel in future operations.

• Characterize the magnitude of DU contamination in gun tubes and equipment used to ventilate gun tubes after firing. Determine the potential for crew compartment contamination from gun bore gases or flashback incidents.

8.2.3 Environmental Policy

Army environmental policy goals must support the Army mission, contribute to readiness, and serve the collective national best interests. In recent years, Congress has substantially increased the breadth and depth of requirements that drive Army environmental policy. The conclusions presented below reflect candidate policy options the Army could invest in to improve environmental management of DU weapon systems. Investment in all Army policies is tempered by the distribution of resources among competing needs.

Environmental Documentation

Army regulations implementing NEPA require program managers to generate and maintain life-cycle environmental documentation for weapon systems. Army policy also requires NEPA documentation for all NRC license applications. The Army should review all current environmental documentation on DU and consider preparing a programmatic LCED. If supported by the

LCED, the Army should explore the need for preparing a comprehensive PEIS that considers all DU weapon systems.

DU Waste Disposal

The Low-Level Radioactive Waste Policy Act and Nuclear Regulatory Commission regulations control DU disposal. The act allows states to create regional compacts for low-level radioactive waste disposal. Compact restrictions regulating the amount of low-level waste that can be sent to regional waste sites could force weapon test sites to retain excess DU waste material. When the amount of DU waste at a test site approaches NRC license limitations, the Army will be forced to either suspend testing or violate the NRC license. The Army should encourage Congress to consider a system that allocates waste according to the value added in each phase of development, testing and fielding a DU weapon system. Under this approach, a proportional share of the waste generated during testing would be charged against the waste disposal capacities of the states that receive economic benefit from the process.

Under the current regulatory framework, the following policy options should be considered:

- Continue to aggressively participate in low-level waste compacts to ensure adequate capacity at both state and regional levels.

- Provide funding to support the current and projected waste disposal requirement at Army testing centers. Capacities for DU storage, recovery, recycling and disposal at Army test centers are inadequate for current and projected demand.

- Develop a viable program for the demilitariza- tion of unspent R&D ammunition. Currently, unspent R&D

ammunition containing DU is counted against the NRC radioactive material budget for Army testing centers. When testing is complete, the remaining ammunition permanently reduces the radioactive material budget at the test centers.

- Develop waste disposal options, including volume reduction, waste minimization, waste form modification, and waste disposal facilities.

Test and Evaluation Range Management

The only systematic DU contamination of Army land occurs during the RDT&E cycle for DU ammunition. The following techniques could help the Army better manage DU contamination of test ranges:

- Plan site-remediation activities on Army installations to be consistent with long-term land-use goals. Consider the environmental impacts of remediation options when determining future land use.

- Develop a strategy to address the long-term liabilities from DU contamination on test ranges and perhaps on battlefields. This may require examining information on the early research and testing of weapons containing DU.

- Separate high-explosive ranges from new DU ranges so that DU recovery efforts will not be complicated by unexploded ordnance.

- Require catch boxes on all DU ranges because the boxes reduce the amount of DU available to migrate, contaminate, or expose ecosystems. The expense of periodically remediating contaminated sand to recover DU in catch boxes will increase the cost of testing DU penetrators. However, remediating a catch box is

cheaper in the long term than remediating thousands of acres of a DU-contaminated test range.

- Maximize recovery of DU penetrators at test ranges.

- Maximize DU recycling within the Army.

Recovering and reusing DU may reduce long-term liabilities for disposal and remediation. Efforts to recycle DU materials and to generate markets for these materials should be continued; however, the Army should recognize that DU testing will always produce wastes.

- Provide a means to ensure timely disposal of DU waste from test ranges.

Range Assessment and Remediation

Environmentally and financially sound remediation of DU contamination on Army test ranges requires an understanding of the fate and effects of DU. Therefore, site assessments, application of fate and effect models, and estimation of environmental risks and costs are all prerequisites to test range closure. A DU-contaminated range with DU cannot be efficiently remediated without a comprehensive contaminant survey and a risk assessment. These are not possible without well-crafted transport models that can predict DU migration and transformation. Many of the protocols and models required to construct DU models have been developed for application to other waste materials. However, a substantial effort is needed to adapt information to DU migration on Army test ranges. The adapted models would allow the Army to achieve a long-term, comprehensive, environmentally astute DU remediation program for test ranges.

Some of the immediate requirements are described below:

- Fund site investigations, research into remediation technologies and remediation activities.

- Evaluate the effectiveness and cost of remediation technologies (proposed and existing). Define the research requirements necessary to support the development of promising remediation technologies.

- Develop theoretical models that can be used to plan the most cost-effective experiments.

- Evaluate the environmental fate and effects of DU on U.S. test ranges. A better understanding of DU contamination at test ranges could produce data and models transferable to other sites, including battlefields.

- Review environmental and health hazard data obtained to date to ensure that they are consistent and scientifically defensible.

- Review DU-particle data from Army studies and elsewhere to determine data gaps.

- Develop and conduct experiments to generate the requisite data to fill these gaps. Data on DU-chemical species, mass-mean size, surface-mean size, size distribution, specific gravity by species and particle shape are required to support transport and risk models.

- Develop a better understanding of DU particles generated in fires or from hard-target or soft-target impacts.

- Develop environmental fate and effect models to determine relative risk as a function of migration. These models should be robust enough to provide defensible

estimates of the air, surface water, groundwater, and soil migration of DU on test ranges and other contaminated sites.

- Apply data and models that were developed to determine the risks and costs associated with remediating areas contaminated by DU. Developers and PMs could use this data to estimate remediation costs in life-cycle cost analyses for weapon systems containing DU.

- Recognize that data base sampling costs would be inversely proportional to the environmental concentration of DU. Thus, highly contaminated analogs might provide particularly cost-efficient test beds for developing an environmental migration model. The Desert Storm battlefields may also offer some opportunities as analogs for environmental migration.

8.2.4 Battlefield Assessment and Remediation

Remediation of battlefields is not historically the responsibility of the victor. This task typically belongs to the indigenous population. However, it may be appropriate for the Army to be prepared to provide guidance to other governments on the health and safety risks associated with DU for affected battlefields. It may also be appropriate to provide information on environmental measurement, monitoring, migration, and remediation techniques. From this perspective the Army is considering the following actions:

- Defining methods, including the salvage and use of maintenance and repair records to better characterize DU contamination in battlefield areas.

- Evaluating the forms of DU that are present and their transport characteristics under the soil/climate conditions in Southwest Asia. Most DU ammunition

expended in Desert Storm was used on practice ranges. These firing sites are ideal for gathering data that could be used to verify theories on DU's environmental behavior. These sites also could provide valuable information for calibrating a risk/cost model.

- Evaluating fire and battle sites in Southwest Asia.

These sites may provide valuable data to help develop accurate environmental models. Characterizing these sites may provide evidence of the environmental impact of DU on the battlefield.

8.3 Caveat Emptor

Actions to implement the policies suggested by the findings and conclusions in this report should be weighed against the costs associated with the environmental safety and health issues presented. Decisions must be framed to ensure that the studies have the potential to mitigate the real costs of remediation and health management as related to Army DU-weapon systems.

SUMMARY REPORT TO CONGRESS

HEALTH AND ENVIRONMENTAL CONSEQUENCES OF DEPLETED URANIUM USE BY THE U.S. ARMY

Prepared By

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Purpose

A recent report by the United Kingdom Atomic Energy Authority warned about possible long-term consequences of depleted uranium (DU) left on the battlefield in the Persian Gulf. As a result, Congress directed the Army Environmental Policy Institute to conduct a study to determine:

1. The health and environmental consequences of using DU on the battlefield
2. Which remediation technologies exist or might be developed to clean up DU contamination
3. Ways to reduce DU toxicity
4. How to best protect the environment from the long-term consequences of DU use.

The Army Environmental Policy Institute, under the direction of the Office of the Secretary of the Army, conducted a study on the health and environmental consequences of DU. The Institute assembled a team of health, environmental, systems and legal professionals to review the technical literature, statutes, policies, procedures, regulations and training programs relevant to the Army's use of DU. The team also conducted interviews to assess the adequacy of technical understanding, procedural control and regulatory compliance with respect to the Army's use of DU.

Although this report does not directly address DU weapon systems produced by the Department of Energy (DOE) or used by other services, (i.e., the Air Force or Navy), the health and environmental consequences associated with using these systems should be similar.

If providing the fighting soldier with the maximum battlefield advantage means using DU, then methods to minimize potential health and environmental consequences must be employed. It should be noted that under current international law, there is no legal requirement to remediate environmental damage to battlefields. Furthermore, it is unlikely that future remediation of battlefields solely to remove DU will be required.

Background

The DU Production Process

Depleted uranium is a byproduct of fuel- and weapons-grade uranium refining. While naturally occurring uranium, a radioactive element, contains a small amount of the isotope ^{235}U, nuclear power requires greater concentrations of ^{235}U to sustain the nuclear chain reaction. The process to concentrate the ^{235}U is called enrichment. One byproduct of the enrichment process is depleted uranium. DU retains uranium's natural toxicological properties and approximately half of its radiological activity. As such, DU is treated as low-level radioactive material and, when discarded, is considered a low-level radioactive waste (LLRW). It fits into the lowest LLRW hazard class.

When properly managed, low-level radioactive waste does not present a significant chemical or external radiological hazard.

Commercially, DU is used in medicine, space, aviation and petroleum exploration. Particular applications include radiation shielding for the medical field and industry; counterweight components of aircraft elevators, landing gear, rotor blades and radar antennae; ballast in satellites, missiles and other crafts; and drilling equipment used in petroleum exploration.

In military applications, when alloyed, DU is ideal for use in armor penetrators. The photo on page 3 shows a typical DU cartridge and penetrator. These solid metal projectiles have the speed, mass, and physical properties to perform exceptionally well against armored targets. DU provides a substantial performance advantage, well above other competing materials. This allows DU penetrators to defeat an armored target at a significantly greater distance. Also, DU's density and physical properties make it ideal for use as armor plate. DU has been used in Army systems for many years in both applications. Over the past 20 years, the Department of the Army (DA) has developed, tested and fielded a number of weapon systems containing DU. The United States is not alone. The United Kingdom, Russia, Turkey, Saudi Arabia, Pakistan, Thailand, Israel, France and others are developing or already have DU-contain-

ing weapon systems in their inventories. The use of DU weapons and armor during Desert Shield/Desert Storm has lead to public concern over the health and environmental risks of DU. As a result of friendly fire incidents, approximately 22 soldiers from Desert Storm may have retained embedded DU fragments. This is a combat injury never before encountered. Additionally, a January 1993 General Accounting Office (GAO) report found that the Army did not have a comprehensive DU battlefield management plan. This study also reported that Desert Storm recovery and maintenance soldiers worked in and around DU-contaminated equipment without being aware of their potential exposure and without being appropriately trained in protective measures. The GAO also reported that Army training on DU safety is not routinely provided to many personnel who could come in contact with DU-contaminated equipment.

During Desert Shield/Desert Storm, the Army fired DU munitions at practice firing ranges and during battle in Southwest Asia. The Army has also tested DU munitions at specific U.S. sites while developing and producing weapon systems.

The Army has considerable experience in managing the environmental issues associated with DU on test ranges in the United States. For many years, the Army has conducted tests in enclosed chambers in which a DU penetrator strikes armor plate (hard-target testing). The enclosure precludes the DU-containing aerosols (suspensions of small particles that can be generated upon impact) from being transported through the air. Work is ongoing to evaluate if and how DU migrates on the soft-target (cloth or wood and soil impact) test ranges. Experiments have been conducted to determine the extent of contamination resulting from fires in vehicles that contain DU.

Efforts to better define all of these issues are in progress. Specifically, environmental fate and effect studies designed to assess the risks of residual DU on the ranges will be expanded to include transport models to more accurately evaluate environmental risks. The Army has had active DU range recovery programs, designed to remove DU from the environment, in place for many years. These programs are continually being improved.

Because Desert Shield/Desert Storm was the first battlefield use of DU, the Army is considering all of the experience gained to develop programs that will address issues identified during and after the conflict. Generalized environmental risk/cost policy models are being considered to enhance fate and effect evaluation of DU migration across many soil and environmental conditions. Additional data on DU particulates generated during hard-target hits and DU-containing fires will be required for these models. These data also will improve health effect models for wound contamination and inhalation exposures. Finally, data exchanges are being pursued with other countries to minimize the costs and to maximize the accuracy of environmental models that can be used to better assess the impacts of DU on the environment and human health.

The first U.S. battlefield use of DU has clearly presented new areas requiring attention, including the need for more data on potential health and environmental consequences associated with the chemical and radiological characteristics of DU. A significant effort is underway to evaluate the long-term health risks to the U.S. soldier in light of the acknowledged characteristics that make DU desirable for use in weapons systems. Thirty-six U.S. soldiers (including the 22 suspected of retaining embedded fragments) have sought or reported for medical treatment as a result of being in vehicles that were struck by DU munitions. The Army and the Department of Veterans Affairs (DVA) have, with the assistance of the Armed Forces Radiobiology Research Institute (AFRRI), initiated a peer-reviewed program designed to provide health care monitoring and treatment for individuals suspected of incurring injuries from, or internal exposure to, DU. These soldiers will be monitored for at least five years.

The Army Environmental Policy Institute examined the life cycle of DU in Army weapon systems, which include penetrators and tank armor. The purpose of this study was not to verify the technical performance of DU weapon systems; the study accepts as fact that the superior performance characteristics of DU precipitated informed decisions about weapon selection. Instead, this report assesses the health and environmental effects associated with the use of DU.

Results in Brief

Previous Research

The Department of Defense (DOD) and the Department of the Army, prior to fielding DU-containing weapon systems, considered the health and environmental consequences, based upon two independent and three internal investigations:

- The National Materials Advisory Board of the National Research Council (part of the National Academy of Sciences) conducted two independent assessments of DU. The first, a generic assessment conducted in 1971, and the second, a specific assessment completed in 1979, compared DU penetrators with tungsten penetrators, the next best alternative.
- Between 1974 and 1989, DoD and DA commissioned three studies on the health and environmental effects of DU. The Office of the Director, Defense Research and Engineering, tasked the Joint Technical Coordinating Group for Munitions Effectiveness to perform an initial assessment to "…evaluate the medical and environmental implications of the use of depleted uranium (DU) and alternatives in a variety of conventional munitions." This review was published in 1974. The former Assistant Secretary of the Army, the Honorable Percy Pierre, requested the second study. A group of primarily non-DoD scientists prepared the Pierre Report, published in 1979. A group of DoD and non-DoD scientists completed the third study, the Danesi Report, at the request of the Army Materiel Command. It was published in 1989.

Current Study Results

Conclusions from the AEPI study, concerning both environmental and health impacts related to Army use of DU, support previous findings and are summarized in the remainder of this section.

Health Risks—Peacetime Operations.

The health risks associated with using DU in peacetime are minimal. This includes risks associated with transporting, storing and handling intact DU munitions and armor during peacetime. The risks are within current safety and health standards and are controlled by the Army's radiation protection program.

Health Risks—Battlefield Operations.

A review of the experimental data and the lessons learned in Operation Desert Storm led to the following conclusions:

- It is highly unlikely that DU is a contributing factor to the unexplained illnesses currently being reported by veterans of Desert Storm. This conclusion is based on the assessment that there was little or no internal DU exposure by most Desert Storm soldiers.
- The potential for health effects from external DU exposure during combat operations is not significantly greater than the potential during peacetime operations.
- The friendly fire incidents that occurred during Desert Storm showed that personnel in armored vehicles can survive DU penetrations of their vehicles but that they can have medically significant internal DU exposure from embedded fragments, wound contamination and inhaled aerosols.
- The Office of the Army Surgeon General believes that the long-term health effects of embedded DU fragments have not been well defined but are minimal. The long-term medical follow-up of veterans with embedded DU fragments is in progress and will continue. In most instances, the DU fragments were allowed to remain embedded because the number and location of those fragments made the risks of physical removal significant. These cases will initially be monitored in a five-year study by the Army and the DVA. If necessary, the Army will monitor these patients for longer periods. Monitoring data will be used to better define the risks from embedded DU fragments.

- It is unlikely that recovery and maintenance personnel working in and around vehicles impacted by DU penetrators received significant internal DU exposure. Because the risks have not been well defined, the Army is monitoring those soldiers who worked extensively with DU-contaminated vehicles and may have sustained exposure. Data from these studies will be used to develop models that predict health risks and to design protective measures, if required, for maintenance and recovery personnel. It is unlikely that significant internal exposures occurred to other individuals who either had incidental contact with contaminated vehicles or breathed smoke from the plumes from burning vehicles impacted by DU penetrators. These scenarios, however, should be evaluated to quantify the risks.

Environmental Risks—Peacetime Operations.

A number of studies concerning the environmental risks of the peacetime uses of DU have been accomplished. Following are the major points identified concerning risks during peacetime operations:

- The Army has been aggressive in managing DU on test ranges to reduce the environmental contamination at these facilities and has initiated programs to model the environmental fate and effects of DU. The effectiveness of these programs could be improved by more comprehensive modeling and experimentation efforts.

- The Army continues to develop policies and procedures for recovering and managing DU-contaminated test areas. Additional data are required to evaluate and enhance the effectiveness of these policies and procedures.

- The Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) and other environmental laws and regulations the the Environmental Protection Agency (EPA) and Nuclear Regulatory Commission (NRC) administer require that all federal lands, including test ranges, be cleaned up before they are released for unrestricted use under the Base Realignment and Closure program. The environmental impacts of remediation alternatives will be considered in determining future land use.

Environmental Risks—Battlefield Operations.

The major points indentified in this study concerning battlefield operations follow:

- The postwar battlefield is a dangerous place. It is contaminated with many environmentally harmful substances.

- The impact of DU and other contamination on the battlefield is not well defined. Relative to many of the other hazards, however, the DU impact is probably small.

- Any guidance the United States provides, consistent with U.S. foreign policy, to affected nations to assist them in cleaning up battlefield debris should be based upon our best estimate of the short- and long-term environmental consequences. DU management should be included as part of any remediation program recommended to a host nation to mitigate environmental damage on the battlefield.

- The potential for major environmental impact from DU contamination on battlefield sites is low. Additional environmental modeling and data are needed, however, to support this judgment.

Remediation Technologies.

Very few technologies have been applied to remediate sites contaminated with DU. There is a paucity of data on the success of these efforts. However,DU is a heavy metal,and many of the technologies used for segregating other heavy metals such as gold, lead and cadmium may be effective in cleaning up DU.

Measures to Reduce DU Toxicity.

The inherent chemical and radiological toxicity of DU cannot be significantly changed. DU must be managed carefully and appropriately in light of these risks.

Principal Findings

Uranium/Depleted Uranium Properties and Characteristics

DU is Chemically Similar to Uranium but is Radiologically Different.

Uranium is a radioactive heavy metal nearly twice as dense as lead. It occurs naturally in a variety of forms. Uranium readily combines with other elements to make uranium oxides, silicates, carbonates and hydroxides. It can be purposely combined with other metals to create readily machinable, high strength alloys. Small particles of uranium metal can ignite spontaneously in air and can burn rapidly at very high temperatures.

Three naturally occurring isotopes of uranium are found in the earth's crust: uranium-234 (^{234}U), uranium-235 (^{235}U) and uranium-238 (^{238}U); each is radioactive. Of these isotopes, ^{238}U is the most abundant (more than 99 percent of natural uranium) and has the lowest rate of radioactive emission. If the radioactivity of ^{238}U were equal to one, ^{235}U would have a radioactivity of approximately seven, while ^{234}U would have a radioactivity of about 18,000. Thus, ^{234}U is a major contributor to the radioactivity of natural uranium and DU, though it represents less than one percent of the total weight.

Depleted uranium is a byproduct of the process in which uranium is enriched to become reactor fuel or weapons-grade material. DU is about half as radioactive as naturally occurring uranium because it contains less ^{234}U and ^{235}U.

DU Applications and Use

In addition to military weapon systems, DU is used commercially in medicine, aviation, space and petroleum exploration. Particular applications inclued radiation shielding for the medical field and industry; counterweight components of aircraft elevators, landing gear, rotor blades and radar antennae; ballast in satellites missiles and other crafts; and drilling equipment used in petroleum exploration. In military applications DU is used in penetrators, armor plate and, in small quantities, as a catalyst in some mines.

Health and Environmental Attributes

Army Program to Review Health and Environmental Effects of All New Systems.

The Office of the Army Surgeon General reviews all Army weapon systems to assure all known health issues have been satisfactorily addressed prior to fielding. The program managers and various Army agencies also evaluate these systems relative to their environmental consequences under the criteria in the National Environmental Policy Act (NEPA).

DU Toxicological and Radiological Health Effects.

Like naturally occurring uranium, DU has toxicological and radiological health risks. Toxicologically, DU poses a health risk when internalized. Radiologically, the radiation emitted by DU results in health risks from both external and internal exposures; however, the external exposure risk is very low. The magnitude of the toxicological and radiological health risks of internalized DU is dependent on the amount internalized, the chemical form and the route of entry into the body. DU can be interalized through inhalation, ingestion, wound contamination and, as in the case of DU fragments, injection. Both non-combat and combat scenarios can lead to DU health risks.

In non-combat scenarios, inhalation can occur during DU munitions testing, during accidental fires at facilities storing munitions or fires in vehicles loaded with munitions, and during operations that can resuspend DU particulates. Ingestion can occur from hand-to-mouth transfer of contamination or as the result of DU-contaminated food or water. Army safety and health programs are in place to minimize such exposures.

In combat, DU wound contamination and fragment implantation become more significant pathways of entry. The potential for inhalation and ingestion (from DU particles generated when DU penetrators strike armored targets, when DU armor is impacted or when fires consume DU penetrators) also increases. Based on the lessons learned in Desert Storm, the Army is developing procedures to better manage the internal exposure potential for DU during combat. As previously stated, external exposure

issues do not differ significantly between combat and non-combat situations, and they pose minimal risk.

Radiological exposure to external sources of DU occurs through the proximity of personnel to munitions, armor and contaminated equipment. These are low-level, low-dose-rate exposures that are within current NRC safety and health standards.

Radiological Risks Not Completely Understood but Not Underestimated.

While there are no data that can be used directly to establish the human cancer and hereditary risks from low-level, low-dose radiation, there is general agreement that the models currently in use do not underestimate either the cancer or hereditary risks.

External Exposures Estimated and Found to Be Minimal.

The Army has extensively studied the external exposures that personnel receive during each phase of the DU munitions and armor life cycle. These data were developed based on radiation field strength measurements and time/motion studies used to determine exposure rates and cumulative doses. The Office of the Army Surgeon General fully reviewed all data relative to health assessment. The radiation exposure depends upon the amount of DU, the DU item (penetrator or armor), the configuration (storage, uploaded on a vehicle, exposed penetrator), and the time and distance over which the exposure occurs. The designs of the DU munitions and the DU armor minimize the external exposures to the crews and handlers; the DU is always encased by non-radioactive materials. For all Army DU systems, the exposure to soldiers and civilian employees associated with those systems is less than five percent of the current NRC occupational worker exposure limit of 5,000 millirem per year.

Internal Exposures for Some Personnel Wounded in Friendly Fire Incidents Potentially Significant.

Once internalized, DU delivers radiation exposure to the site of contact, as well as to other organs in the body to which uranium migrates. A number of methods have been developed to determine how DU migrates within the body based on the type of exposure, DU form, time, degree of exposure and pathway of internal migration. Techniques exist to assess the level of uranium internalized by inhalation or ingestion. While some best professional judgment estimates can be made, models to estimate more accurately the radiation exposure from uranium internalized by wound contamination or from embedded DU fragments are not now available.

During Desert Storm some U.S. soldiers unfortunately sustained penetrating wounds in friendly fire incidents. Some of these soldiers had multiple (up to 30) fragments ranging in size from one millimeter to 20 millimeters in diameter in their bodies. Upon review of these injured soldiers' medical records, the Office of the Army Surgeon General identified 22 who may have retained embedded DU fragments. In most instances, the fragments were allowed to remain embedded because the numbers and locations of these fragments made the medical risks associated with surgical removal unacceptable. The Army and DVA will continue to monitor these cases as part of a five-year study.

The Armed Forces Radiobiology Research Institute conducted an extensive literature search on the health effects of allowing DU fragnments to remain embedded in the body and concluded that there was no compelling reason to change current surgical criteria for fragment removal. This same study cited two as-yet undefined key uncertainties that could change this recommendation: (1) the long-term radiation effects on the tissue surrounding the fragment and (2) the long-term toxicological effects of embedded DU.

Toxicological Risks Not Completely Understood.

Like most heavy metals, uranium is chemically toxic if sufficient quantities are internalized. Once incorporated, the highest concentrations of uranium are found in the kidneys, liver, and bone. The kidney is the most sensitive organ to toxicity. It is important to realize, however, that uranium is found throughout the environment and is naturally incorporated into the body.

The toxicity of internalized DU depends on:

- Amount internalized
- Route of internalization

- Physical characteristics of the DU internalized
- Chemical solubility characteristics of the DU internalized.

The generally accepted threshold for kidney toxicity set by the NRC in 1959 is still used today. The literature, however, reflects great discussion concerning this limit, particularly in light of recent studies showing toxic effects occurring at lower relative levels in animals.

Another area of uncertainty concerns exposure of female soldiers to DU. At present, there are no definitive studies on the health and developmental effects on fetuses whose mothers have internalized DU. It is important to note, however, that no female soldiers were involved in the friendly fire incidents and none served on the recovery and maintenance teams.

Chronic kidney toxicity and localized radiation effects are the primary health concerns for Desert Storm veterans wounded by DU fragments. Embedded fragments have resulted in elevated levels of uranium in the blood. These veterans are being monitored by the DVA/Army five-year study.

Definitive Health Risk Conclusions Difficult.

It is difficult to present a conclusive discussion of the risk associated with the exposure to low-level radiation from DU because adverse effects of very low levels of radiation are difficult to document in humans.

Studies summarized by the National Research Council on the effects of low-level exposure did not reveal a significant increase in radiation effects on workers or populations living near nuclear installations,exposed to nuclear weapons fallout,exposed to medical radiation, or living in high natural background radiation areas.

The National Research Council did not discount hereditary or cancer risks associated with low-level radiation exposure, but it did draw two conclusions: (1) the available data did not allow a direct estimate of the risk from low levels of radiation; and (2) the data indicated that current risk estimates do not underestimate the risk and probably represent the upper bound of real risk.

The following should be kept in mind during any consideration of the health effects of low-level radiation:

- The general public is continually exposed to radiation from natural sources. The average annual radiation background exposure in the United States is about 300 millirem from natural sources. The NRC exposure standard for the general public is 100 millirem per year above background.
- It is typically impossible to determine whether a specific cancer or hereditary effect occurred naturally or was the result of low-level radiation exposure. No medical difference exists between naturally occurring or radiation-induced cancer and hereditary effects.
- NRC and EPA have established radiation standards to protect radiation workers and the public from significant risks.
- High local doses, such as those received by tissues surrounding an embedded fragment, do not correlate well with published cancer risk data because these data are typically calculated using whole-organ or whole-body doses. Thus, existing models cannot estimate the health risk to soldiers with embedded DU fragments.

DU May Become Mobile in the Environment.

Because DU and naturally occurring uranium are chemically the same, knowledge about the transformation, transport, fate and effect of natural uranium in the environment is applicable to the study of DU.

Uranium, like other metals, will oxidize under most environmental conditions. Variables such as temperature, metal size and shape, presence or absense of coatings, and water and soil contaminants control the oxidation rate.

Under some conditions, such as those in swamps and wetlands, DU oxidizes to a state where it will not readily dissolve in water and thus becomes relatively immobile. Under other conditions, such as on the surface of the ground or in shallow water, DU oxi-

dizes to a state where it can dissolve and become mobile in water. Small DU particles, such as fragments and abrasion particles, will oxidize faster; large pieces, such as nearly whole penetrators and large fragments, will oxidize more slowly.

Water is the dominant mechanism for transporting all metals, including DU, in the environment; metals may move in surface waters or groundwater. For metals widely dispersed across a land surface, the principal concern is groundwater contamination, although erosion can result in contaminated water runoff to surface streams and ponds. In arid environments, the wind can transport dust contaminated with small DU particles.

The Army has used three principal centers for test firing DU penetrators:

- Aberdeen Proving Ground, Maryland
- Jefferson Proving Ground, Indiana
- Yuma Proving Ground, Arizona.

Firing sites at these three centers have been surveyed to evaluate transport mechanisms under a variety of environmental conditions. Because the radiological signature of DU is unique, it was possible to distinguish DU contamination from naturally occurring uranium sources. Environmental monitoring studies at these firing sties did not find DU migration out of the impact areas, although the studies did find some evidence of limited migration within the impact areas. It should be recognized, however, that the data from these sites cannot be broadly generalized for other sites.

Groundwater at Aberdeen Proving Ground and Jefferson Proving Ground was analyzed; no DU was detected. Groundwater at Yuma has not been analyzed because the semiarid climate and the soil chemistry at Yuma made it unlikely that DU could ever reach the first aquifer at the 700-foot level. At Aberdeen, localized soil contamination was discovered at depths of 20 centimeters (7.9 inches) below a penetrator corroding on the soil surface. This suggested that DU can become soluble and migrate to a limited degree even through soil in a wetland environment. At Yuma, where a high evaporation rate results in little vertical infiltration, soil contamination near a corroding penetrator decreased to background levels at a depth of eight centimeters (3.2 inches). Sediment samples in an adjacent drainage channel, however, contained DU, presumably from storm runoff.

Other studies at the firing areas revealed that DU contamination occurs (1) at shallow depths immediately downrange from the gun tun; (2) where penetrators first pass through the soil ("skip" areas); and (3) in the final landing area. The low level of contamination immediately downrange from the gun tube occurs due to fragments from malfunctioning rounds and very low levels of DU emitted during normal firing operations. In the skip aras, soil contamination results from abrasion fragments of the penetrator, and in the final landing area, from corrosion.

Investigations of DU migration at U.S. test sites have not identified significant migration in the environment. It is fortunate that the environmental conditions, particularly the water and soil conditions, at the three major test locations tend to prevent soluble DU-containing compounds from forming and thus limit environmental migration. However, because future uses of DU, particularly in combat, will not be restricted to these ranges, the Army is developing risk models to ascertain ways to predict the environmental mobility DU under any soil condition.

Potential DU External Radiation Exposures Were Below the Annual Limit for the General Public

During Desert Shield/Desert Storm, the Abrams tank crews were exposed to low levels of DU radiation in the crew compartment from DU armor (Abrams heavy tank only) and from combat ammunition storage. Predictable dose rates for crew members can be determined by combining vehicle occupancy rates with actual radiation measurements. A typical exposure rate inside a tank is 0.1 millirem per hour, thus, a crew member could stay for a total of 1,000 hours per year before exceeding the new NRC 100 millirem annual limit on exposure to the general population.

Detectable amounts of DU are deposited in the gun tube when a DU round is fired. Recently completed studies have determined that such contamination poses no significant health hazard to personnel handling the gun tubes. Studies are underway to determine if any significant migration occurs into the

tank crew compartment.

When a DU projectile penetrates an armored vehicle, it may pass completely through the vehicle or ricochet and break into fragments inside the vehicle. In addition to flying metal fragments, crews can be exposed to DU oxides, toxic fumes, smoke and flames. The force of impact will convert a portion of the DU penetrator into aerosols, thereby exposing the crew to respirable particles. The vehicle itself is contaminated with particulates and fragments from the DU penetrator and any DU armor damaged by the impact.

After a battle has been concluded, medical and equipment recovery personnel move onto the field. Damaged U.S. equipment is repaired on site or stripped and/or evacuated to rear maintenance points. Enemy equipment is usually left in place. Equipment contaminated with DU can contaminate personnel and other equipment. DU particulates can be resuspended, blown, washed or dislodged during repair, retrieval or transit.

During Desert Shield/Desert Storm, 15 Bradley Fighting Vehicles and 14 Abrams tanks were contaminated after being hit by DU rounds or after stored DU ammunition ignited due to an accidental onboard fire. In all, 28 of the 29 vehicles were returned to the 144th Service and Supply Company, New Jersey Army National Guard, at King Khalid Military City, Saudi Arabia. The 29th vehicle, an Abrams tank, was damaged by a fire in December 1990 and returned directly to the Defense Consolidation Facility (DCF) in South Carolina in January 1991.

The 144th was responsible for establishing a central receiving and storage point, for assessing battle damage and for preparing the vehicles for return to the United States. Initially, the 144th Service and Supply Company was not familiar with procedures for handling DU-contaminated equipment. For about 3 weeks, up to 25 soldiers may have worked on the DU-contaminated vehicles. These soldiers did not know that the vehicles were contaminated with DU, nor were they aware of necessary protective measures. An Army recovery team arriving from the United States secured all contaminated vehicles, limited access to them, surveyed the equipment, and instituted protective measures such as wearing dust masks and thin rubber gloves and washing hands, faces and clothing.

After fixed radioactive contamination caused by DU penetrator strikes was removed, six of the Bradleys were buried at an approved site at King Khalid Military City. They were not turned in for scrap because they all had burned and the certifying officer could not declare that there was no unexploded ordnance in the wreckage. (When a Bradley burns, the aluminum armor melts into the center of the vehicle. Once it cools and hardens, the metal may cover unstable live ammunition.) DU-contaminated components, as well as the remaining vehicles, were returned to the Defense Consolidation Facility in South Carolina for decontamination, salvage or return to the repair facilities.

DU Contamination in Southwest Asia.

More than 14,000 large caliber DU rounds were consumed during Operation Desert Shield/Desert Storm. As many as 7,000 of these rounds may have been fired in practice. Approximately 4,000 rounds were reportedly fired in combat. The remaining 3,000 rounds are losses that include a substantial loss in a fire at Dohoa, Saudi Arabia. Between 80 and 90 percent of the DU penetrators fired in combat probably came to rest in or near target vehicles. Rounds that missed probably buried themselves near the intended targets or skipped downrange.

Development tests under field conditions show that the highest level of DU contamination is adjacent to an impacted vehicle. This level of contamination is reduced by 90 percent within the first 30 meters, but trace amounts of DU concentrations have been detected out to 400 meters downwind. Vehicles burned with exploding ammunition under test conditions ejected some fragments as far as 65 meters.

Remediation Technologies

DU remediation technologies under development involve one or more of the following: excavation and earth moving, physical separation, chemical separation, and in-place stabilization. Unless in-place stabilization is selected, earth-moving processes are required. The scope of this activity ranges from (1) excavating and disposing of all contaminated soil to (2) excavating, treating and re-emplacing the soil. There are health and environmental hazards associ-

ated with any earth moving project. These are compounded by the toxicological and radiological effects of DU and, more importantly for battlefields and most test range sites, unexploded ordnance.

Physical separation techniques use the characteristics of the containment (density, particle size, shape, etc.) to segregate it from the soil. These techniques range from simply having personnel pick up DU fragments by hand (a technique the Army commonly uses on its test ranges) through increasingly complex technologies such as screening, sedimentation, centrifugation, filtration and reverse osmosis. Physical separation techniques do not change the state of the contaminant.

A number of chemical treatment processes can be used to separate DU from contaminated soil. Although experience in remediating DU contamination is limited, these processes have long been used to separate other heavy metals (lead, gold, silver, cadmium, chromium, etc.) from soils in mining, industry and environmental remediation. The industry standard is soil washing. Soil washing systems first pass a fluid through the soil to dissolve the metal. Then the chemistry of the solution is altered, causing the metal to precipitate. The soil can be excavated or treated in place.

For shallow soil contamination, heavy metals can be stabilized in place. This strategy uses a chemical binding agent that reacts with the metal to render it insoluble under a wide range of environmental conditions. Because the chemistry of DU is similar to that of other heavy metals, applying this technology to stabilize DU in the environment can be expected to be similarly successful. The major disadvantage of in-place stabilization is that the metal remains in the soil and thus, under unforeseen circumstances, could again become mobile in the environment.

DU Toxicity Reduction

The Inherent Chemical and Radiological Toxicity of DU Cannot Be Changed.

No technologies available can change the inherent toxicity of DU. The Army uses good management practices, material control and encasement to limit personnel exposure to DU in armor and munitions throughout their life cycles. Once materials are compromised, however, such as when penetrators are fired or armor is pierced, uranium can then react with other elements contiguous to it in the environment. This can create chemical reactions that may yield compounds with various chemical toxicities. Due to the nature of high-energy penetrator impacts, there are no effective measures that can be applied to reduce the toxicity of spent projectiles. Alternative materials for penetrators, such as tungsten, are less effective yet retain many of the inherent toxicity problems of heavy metals evidenced by DU.

Long-Term Environmental Consequences

Issues Concerning DU Environmental Management on the Battlefield.

To give the U.S. soldier the best battlefield advantage, the United States must continue fielding superior weapon systems.

Using DU on the battlefield poses potential environmental consequences. The question is how to protect the environment and thereby reduce the risks to the soldiers and the indigenous population. Efforts are underway to develop a fundamental understanding of the fate and effect of DU in the environment. But even a unilateral decision by the United States to eliminate DU weapons would not remove DU from the battlefield: the United Kingdom, Russia, Turkey, Saudi Arabia, Pakistan, Thailand, Israel, France and others have developed or are developing DU-containing weapons systems for their inventories. Additionally, DU munitions are sold in the world arms market.

Findings

The Institute's findings presented below address Congress' four areas of concern:

1. *The battlefield is contaminated with many dangerous things. The impact of DU contamination on the battlefield is not well defined. Relative to many of the other hazards, such as unexploded ordnance, the hazards associated with DU contamination are probably small; however, additional environmental modeling and data are needed to support this judgment.*

2. *DU remediation technologies involve one or more of the following: excavation and earth moving, physical separation, chemical separation, and in-place stabilization. The Army will continue to identify and evaluate alternative remediation technologies by comparing the cost and effectiveness. From this analysis, the Army will seek effective, less expensive DU remediation technologies.*

3. *There are no technologies available that can significantly change the inherent chemical and radiological toxicity of DU.*

4. *Range management and DU recovery systems have been implemented and are being improved. Models to better describe the environmental fate and effect of DU are being developed. DU migration on test ranges in the United States has been minimal because the soil and water conditions on those ranges tend to prevent formation of soluble DU.*

Conclusions/Recommendations

Having completed an exhaustive review of weapon systems containing DU, AEPI concludes that the Army has done an excellent job attending to the environmental and health impacts of these systems. The conclusions contained herein describe additional efforts to attain an even higher level of health and environmental security relative to DU. In many cases the Army has already taken action to implement these initiatives. AEPI believes these candidate efforts will further enhance an already well-reasoned program.

Major conclusions are grouped into several categories relating to their effects on health and the environment, peacetime production and testing, and battlefield use.

General

Establish DU Management Office.

Designate a single office, independent of DU systems development or user activities, to manage and control DU health, environmental and regulatory issues within the Army or DoD.

An independent organization overseeing DU use in the Army could improve the coordination between acquisition, use, demilitarization and remediation activities. This DU management office, functioning as the principal expert, would ensure compliance with applicable laws and regulations and would design, coordinate and evaluate health and environmental research programs.

If this DU office consolidated the Army's current 14 Nuclear Regulatory Commission, non-medical DU systems licenses into a single license, the Army would benefit significantly. A single, standardized license administered by this centralized DU management and research authority would alleviate present monitoring, equipment and operational inconsistencies between operating locations.

Revise Army Regulations.

The Army should revise its regulations and policy documents to explicitly link the acquisition, use, safety, disposal, demilitarization and environmental management of DU. This could serve as a model for a DoD-wide system.

When taken individually, the current regulations and policy documents adequately express the environmental, system safety and health hazard assessment issues associated with a weapon system during specific phases of its life cycle. What appears to be lacking in the regulations, however, is an explicit cross-reference between the policies of each regulation. With an adequate cross-reference available, those responsible for acquisition would know about the details expected in the environmental regulations and would become familiar with aspects of the ultimate demilitarization and disposal of the system. DU license holders and specific sites using or storing DU-containing systems would be aware of NEPA requirements relative to DU. Demilitarization and disposal experts would learn what to expect after receiving an obsolete system containing DU.

Analyze Life Cycle Costs.

The Army should determine the full life cycle cost of DU weapon systems. This analysis must take into account not only production costs, but also demilitarization, disposal and recycling costs; facility decontamination costs; test range remediation costs; battlefield cleanup costs; and long-term health and environmental costs.

Test Ranges and Battlefields

Expand Training.

The Army should continue to improve training programs for the wide variety of soldiers and support personnel who may come into contact with DU or DU-contaminated equipment. At a minimum, the Army must include armor, infantry, engineer, ordnance, transportation and medical personnel in this training.

In response to the GAO-documented need for additional training, the Army has initiated actions to develop the training programs mentioned.

Assess Medical Surveillance.

To manage any potential health impacts from the use of DU weapon systems, the Army should:

- Develop a screening protocol and treatment criteria to assess veterans who may have been exposed to battlefield DU.
- Review its standard field medical procedures to ensure they are adequate to treat battle wounds contaminated with DU. Develop a standard DU decontamination medical procedure. Train medical personnel to manage DU health risks.
- Initiate research on the long-term health effects of implanted DU fragments. Develop models to estimate the radiation and toxicological consequences of DU internalized as a result of contamination or embedded fragments.
- Continue to identify personnel who were involved in DU friendly fire incidents, but did not receive injuries. The Army should attempt to identify soldiers whose duties required them to enter DU-impacted Iraqi vehicles. This will ensure that they receive health care monitoring and treatment, and it can provide valuable health data on the potential for inhaling DU-containing aerosols.

Assess Exposure Potential.

- Continue to characterize the magnitude of DU contamination of gun tubes and equipment used to ventilate the gun tube after firing. Determine the potential for crew compartment contamination from gun bore gases or flashback incidents.
- Continue to investigate equipment modifications and procedures to minimize crew exposure to both chemical and radiological hazards from DU.

Environmental Policy

To establish appropriate policy concerning DU, the Army should:

- Continue to maximize recovery of DU penetrators at test ranges and require that high explosive test ranges be separated from new DU test ranges so that future DU recovery efforts will not be complicated by the current problem of unexploded ordnance. Emphasis should be placed on maximizing DU recycling within the Army system.
- Fund recovery, recycling and waste disposal programs adequately, and plan for site remediation on Army installations consistent with land use goals. The environmental impacts of remedial action options will be a consideration in determining future land use.
- Fund development of waste disposal options, including volume reduction, waste minimization, waste form modification and new disposal facility development.
- Review and, if necessary, revise environmental documentation of DU weapon systems and NRC licenses to ensure completeness, accuracy and currency. Army regulations implementing NEPA require program managers to generate and maintain life cycle environmental documentation for weapon systems. Army policy also requires NEPA documentation for all NRC license applications.
- Continue to participate aggressively in low-level waste compacts, at both state and regional levels. Low-Level Radioactive Waste Policy Act and Nuclear Regulatory Commission regulations control DU disposal. The Act provides language for states to create regional compacts for the purpose of low-level radioactive waste disposal. Limitations on the amount of low-level waste that can be sent to the few current waste sites could result in test sites being forced to retain this material and, as such retention approaches NRC license limitations, could limit the Army's ability to conduct further testing.
- The Army should continue to evaluate the environmental fate and effect of DU on U.S. test ranges. A better understanding of DU contamination at test ranges could produce data and models transferable to other sites, including battlefields.

- Upon appropriate request, help host countries to locate and characterize sites used by tank crews for practice with their main guns using DU ammunition. Because the majority of DU ammunition expended in Desert Storm was used in practice, these firing sites are ideal candidates for both characterizing and verifying theories on DU's environmental behavior. Evaluating the DU forms present and their transport characteristics under the different soil/climate conditions of Southwest Asia could also provide valuable information for calibrating a risk/cost model. Fire and battle sites also will provide valuable data to support the development of accurate environmental models. Characterizing these sites will provide conclusive evidence of the environmental impact of DU on the battlefield.
- Consider methods, including salvage, maintenance and repair methods, to better characterize DU contamination in battlefield areas.
- Use the data and models being developed to determine the risks and costs associated with remediating areas contaminated by DU. Accurate costs to remediate test ranges and battle sites may be used in the life cycle cost analyses for DU-containing weapon systems.

Authority

The Army Environmental Policy Institute wrote this summary report, as directed by the Deputy Assistant Secretary of the Army (Environment, Safety and Occupational Health) in response to Senate Appropriations Committee Report Number 102-408. This summary report is based on a detailed technical report, *Health and Environmental Consequences of Depleted Uranium Use by the U.S. Army*, that is available upon written request. Forward requests to:

Office of the Assistant Secretary of the Army
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The Institute's mission is to assist the Army Secretariat in developing pro-active policies and strategies to address environmental issues that may have significant future impacts on the Army. The Institute wrote this report in response to Senate Appropriations Committee Report Number 102-408. The report presented here is based on a detailed technical report, *Health and Environmental Consequences of Depleted Uranium Use by the U.S. Army*, that is available upon written request. Forward requests to:

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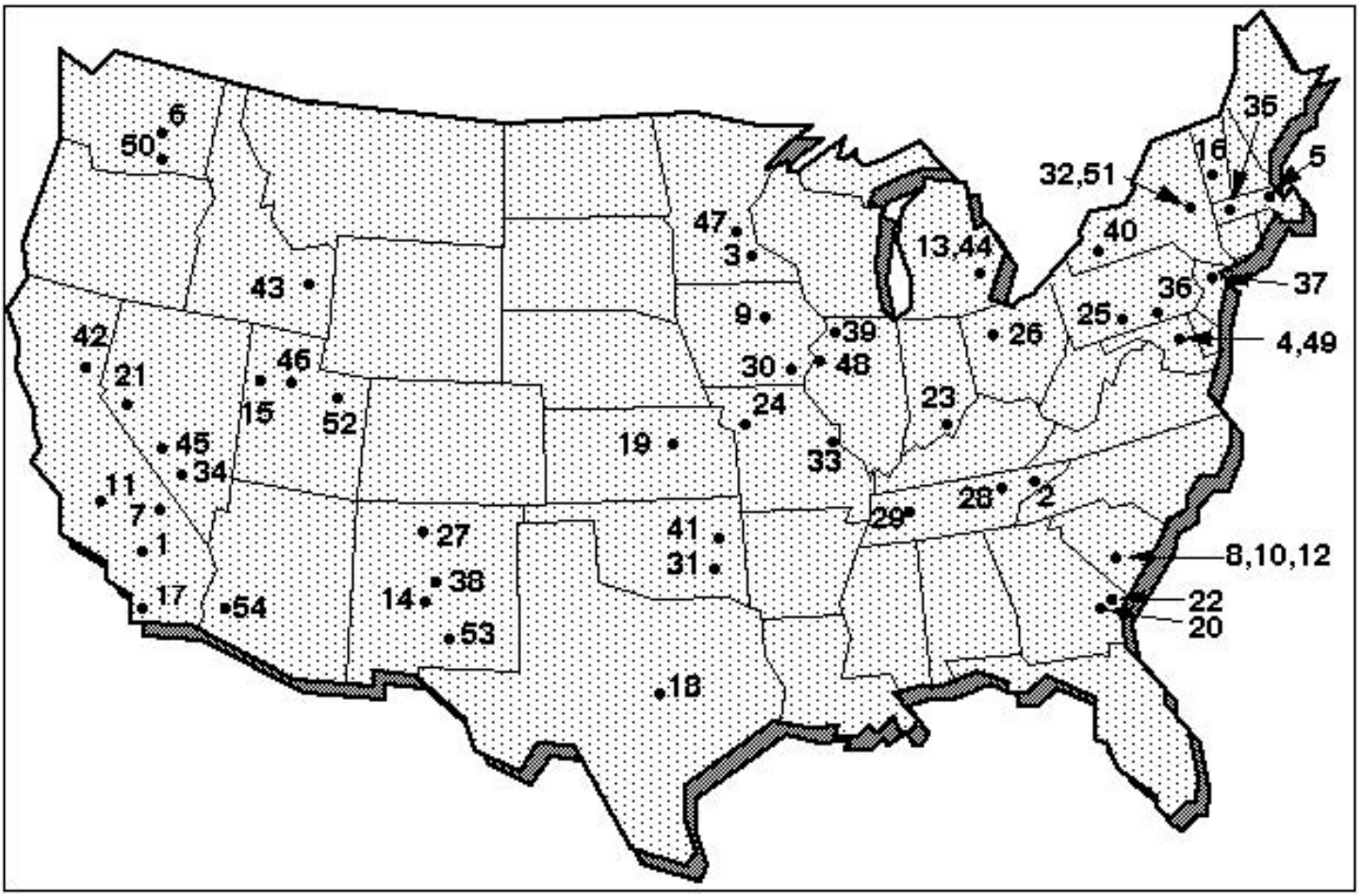

Former DU Use or Storage Sites, and Sites Being Decommissioned

Map #	Name	Activity
3	Alliant Tech Systems, Inc.; Elk River, Minn.	Penetrator testing. Closed, decommissioned, NRC cleared in 1993.
5	Army Research Laboratory, Watertown, Mass.	Former R&D lab (being decommissioned).
7	Camp Roberts Military Reservation; Bradley, Calif.	DU munitions test. ranges. Decontaminated, cleared by NRC in 1986.
9	Chamberlain Manufacturing; Waterloo, Iowa	Projectile assembly (since closed).
11	China Lake Naval Weapons Center Alliant Tech Systems; Ridgecrest, Calif.	Test firing of 120 mm DU rounds for the Army (being decommissioned).
17	FOrd Aerospace and Communications Corp.,, San Juan Capistrano, Calif.	Developed and tested 25 mm DU ammunition.
18	Fort Hood; Killeen, Texas	Stored 105 mm DU munitions 1989-90.
19	Fort Riley; Junction City, Kan.	Stored 105 mm rounds 1989-90. Facility improperly destroyed after damaged.
20	Fort Stewart; Hinesville, Ga.	Stored 120 mm DU ammunition.
24	Lake City Army Ammunition Plant; Independence, Mo.	Former LAP, test range of 20 mm, 25 mm DU ammunition (decontamination planned).
32	National Lead Industries; Colonie, NY	Produced R&D quantities of DU penetrators in 1978-79. Closed 1980.

R&D and Test Sites Involving DU

Map #	Name	Activity
4	Army Research Laboratory; APG, Md.	R&D of DU penetrators and armor.
6	Battelle Pacific Northwest Labs; Richland, Wash.	R^D DU metallurgical analyses; environmental, health hazard studies.
14	Energetic Materials Research and Technology Center, formerly known as the Terminal Effects Research and Analysis (TERA) facility; Socorro, N.M.	Testing by Alliant Tech Systems, Olin Ordnance and Army.
16	Ethan Allen Firing Range (General Electric); Burlington, Vt.	Test 25 mm DU munitions.
23	Jefferson Proving Ground; Madison, Ind.	Test DU munitions against soft targets.
27	Los Alamos National Laboratory; Los Alamos, N.M.	Interior ballistic studies and environmental, health hazard studies.
28	Manufacturing Sciences Corp.; Oak Ridge, Tenn.	R&D of DU armor.
34	Nevada Test Site; Mercury, Nev.	Army DU R&D test.
37	Picatinny Arsenal; Dover, N.J.	DU metallurgical studies R&D facility, former test range.
38	Sandia National Laboratories, Albuquerque, N.M.	Test DU armor and penetrators; weapons containers.
45	Tonopah Test Range; Tonopah, Nev.	Warhead simulation tests.
49	US Army Combat Systems Test Activity; APG, Md.	Research, development and testing of DU penetrators and armor.
54	Yuma Proving Ground; Yuma, Ariz.	Test DU against soft targets.

DU Processing Sites

Map #	Name	Activity
8	Carolina Metals; Barnwell, S.C.	Reduction, casting into DU derby.
41	Sequoyah Fuels Corporation; Gore, Okla.	Convert (UF^6 to UF^4 for AOT.

Waste Disposal Sites Involving DU

Map #	Name	Activity
10	Chem-Nuclear Systems Waste Managemetn Facility; Barnwell, S.C.	Waste disposal.
15	Envirocare of Utah, Inc.; Clive, Utah	DU contaminated soil disposal.
50	US Ecology; Hanford, Wa.	Waste disposal.

Fabrication and Assembly Sites Involving DU

Map #	Name	Activity
1	Aerojet Ordnance Company; Chino, Calif.	Assemble projectiles and Load, Assemble and Pack (LAP) 25 mm DU ammunition.
2	Aeroject Ordnance Tennessee; Jonesboro, Tenn.	Fabricate 25 mm and large caliber DU penetrators.
13	Detroit Army Tank Plant; Warren, Mich.	Assembled heavy armor turrets.
26	Lima Army Tank Plant; Lima, Ohio	Assemble heavy armor turrets.
29	Martin Marrietta Energy Systems Milan Army Ammunition Plant; Milan, Tenn.	LAP large caliber ammunition.
30	Mason and Hanger at Iowa Army Ammunition Plant; Middletown, Iowa	LAP and demilitarize.
33	National Manufacturing Corporation; St. Louis, Mo.	Assemble projectiles.
35	Nuclear Metals, Inc.; Concord, Mass.	Fabricate DU penetrators.
36	Olin Ordnance Corporation; Red Lion, Pa.	Assemble projectiles.
43	Specific Manufacturing Capability Facility Idaho National Engineering Laboratory; Idaho Falls, Idaho	Fabricate DU armor.
44	Tank Automotive Command; Warren, Mich.	Licensee for DU armor.
47	Twin Cities Army Ammunition Plant, Alliant Tech Systems; New Brighton, Minn.	Machine, LAP 25 mm DU penetrators; manufacture molding compound for mines.
52	White Sands Missile Range; Green River, Utah	Missile warhead ballast contamination.
53	White Sands Missile Range; White Sands, N.M.	Missile warhead ballast contamination.

Storage and Storage/Demilitarization Sites Involving DU-Containing Materials

Map #	Name	Activity
12	Defense Consolidation Facility; Snelling, S.C.	DU waste reduction, decontamination.
21	Hawthorne Army Ammunition Plant; Hawthorne, Nev.	Store ammunition.
22	Hunter Army Airfield; Savanna, Ga.	Store 120 mm DU ammunition.
25	Letterkenny Army Depot; Chambersberg, Pa.	Store ammunition.
31	McAlester Army Ammunition Plant; McAlester, Okla.	Store DU ammunitions, contaminated production equipment.
39	Savanna Army Depot; Savanna, Ill.	Store, demilitarize, maintain ammunition.
40	Seneca Army Depot Activity; Romulus, N.Y.	Store, demilitarize ammunition.
42	Sierra Army Depot; Herlong, Calif.	Store, maintain, demilitarize ammunition.
46	Tooele Army Depot; Tooele, Utah	Store, maintain, demilitarize ammunition.
48	U.S. Army Armament Munitions and Chemical Command; Rock Island, Ill.	Licensee responsible for bulk storage.
51	Watervliet Arsenal; Albany, N.Y.	DU munitions applications research; currently stores DU contaminated saw, press, shotblast.

GLOSSARY

Alpha (α) Particle	One of the three primary forms of radioactive emissions from radioactive atoms. Alpha particles are positively charged particles emitted from the nucleus of a radioactive atom. This process is termed alpha decay. Alpha particles have very little penetrating ability and, therefore, are chiefly internal radiation hazards. They travel very short distances in air and are shielded very easily.
Alpha Decay	Radioactivity in which the parent nucleus expels an alpha particle. The atomic number, or nuclear charge, of the decay product is 2 units less than that of the parent. The nuclear mass of the product is 4 atomic mass units less than that of the parent. This is because the emitted alpha particle carries away this amount of nuclear charge and mass.
Beta (β) Particle	One of three primary forms of radioactive emissions from radioactive atoms. A beta particle is a negatively or positively charged particle, electron or positron, emitted from the nucleus of a radioactive atom. Beta particles usually travel greater distances in air than alpha particles and have an intermediate penetrating ability, but still can be easily shielded with common materials.
Beta Decay	A type of radioactivity in which the parent nucleus emits a beta particle. There are two types of beta decay established: in negatron beta decay (β^-) the emitted beta ray is a negatively charged electron (negatron); in positron beta decay (β^+) the emitted beta ray is a positively charged electron (positron). In beta decay the atomic number shifts by one unit of charge, while the mass number remains unchanged.
Bustle	A projection at the rear of an M1 or M1A1 tank turret that stores ammunition.

Complex Compound	Any of a group of chemical compounds that includes coordinate molecular bonding.
Complexing Agent	A substance capable of forming a complex compound with another material in solution.
Curie (Ci)	A quantity of radioactive material that produces 37 billion nuclear transformations per second.
Derby	Depleted uranium metal stock.
Dose Equivalent	The amount of material absorbed in tissue when all modifying factors have been taken into accounts; measured in rems.
Effective Dose Equivalent (H_e)	The sum of the products of the dose equivalent to the organ or tissue and the weighing factors applicable to each of the organs or tissues that are irradiated. The method for calculating H_e is outlined in ICRP Publication No. 26 (ICRP, 1977).
E_h or E_H	See Redox Potential.
Erg	Unit of energy or work, expressed as dyne-cm.
Fission	The process by which a radioactive isotope decays by splitting into two large, usually radioactive fragments. This process also releases energy.
Gamma (γ) Ray	One of three primary forms of radioactive emissions from radioactive atoms. A gamma ray is not particulate (as opposed to alpha and beta particles), but is short-wavelength electromagnetic radiation that also exhibits particle properties associated with photons. Gamma rays are the most penetrating form of radiation and travel great distances in air before absorption. They require heavy shielding materials, such as lead.

Gamma Ray Decay	A transition between two excited levels of a nucleus or between an excited level and the ground level. Gamma ray decay only occurs after another radioactive decay process or after some other process that leaves the product nucleus in an excited state.
Half-life, radioactive	The time (on average) it takes half of the atoms in a sample to decay. The shorter the half-life, the more rapidly it decays, and the more radioactive the isotopes.
Isotope	One of two or more species of an element with the same number of protons in the nucleus but different numbers of neutrons. Isotopes differ in mass and radioactivity but chemically are the same element.
Joule	The unit of energy or work in the meter-kilogram-second system of units, equal to the work done by a force of 1 newton magnitude when the point at which the force is applied is displaced 1 meter in the direction of the force. Symbolized J. Also known as Newton-meter of energy.
Metal	An opaque crystalline material usually of high strength with good electrical and thermal conductivities, ductility, and reflectivity. These properties are related to the structure, in which the positively charged ions are bonded through a field of free electrons, which surrounds them forming a close-packed structure.
Metastable State	In quantum mechanics, an excited stationary energy state whose lifetime is unusually long.
Mineral	A naturally occurring substance with a characteristic chemical composition expressed by a chemical formula; may occur as individual crystals or may be disseminated in some other mineral or rock. Most mineralogists include the requirements of inorganic origin and internal crystalline structure.
Neutron	An elementary particle with approximately the same mass as the proton but lacking a net electric charge.

Nuclear Reaction	A reaction involving a change in an atomic nucleus—such as fission, fusion, neutron capture, or radioactive decay—as distinct from an ordinary chemical reaction, which is limited to changes in the electron structure surrounding the nucleus.
Oxide	A binary chemical compound in which oxygen is combined with a metal or nonmetal.
pe or pE	A measure of relative electron activity. See also Redox Potential.
pH	A term used to describe the hydrogen ion activity of a system; a solution of pH 0 to 7 is acid, pH of 7 is neutral, and pH 7 to 14 is alkaline.
Positron	An elementary particle having mass equal to that of the electron, and having the same spin and statistics as the electron but a positive charge equal in magnitude to the electron's negative charge.
Rad	A unit of adsorbed dose: One rad is 0.01 Joule absorbed per kilogram of any material. (Also defined as 100 ergs per gram and written "rad"). It is being replaced by the gray (Gy). One rad equals one hundredth of a gray.
Radioactive, Radioactivity	Radioactivity is a phenomenon whereby the nuclei of certain atoms experience a spontaneous but measurably delayed nuclear transition or transformation with the resulting emission of radiation. A radioactive material, according to 49 CFR 174.403(y), is any material with more than 0.002 micro-curies per gram.
Radioisotope	Atomic nuclei are of two types, unstable and stable. Those in the former category are said to be radioactive and eventually are transformed, by radioactive decay, into the latter. One or more of the three types of radioactive emissions (α or β particles or γ-rays) occurs during each stage of the decay.

Redox Potential	Measurement of the state of oxidation of a system. Also known as oxidation-reduction potential. Redox level can be expressed in units of volts (E_h or E_H) or units of electrical activity (pe or pE).
Rem	A measure of the dose of any ionizing radiation to body tissues in terms of its estimated biological effect relative to a dose of one roentgen (r) of X-rays. (One millirem (mrem) = 0.001 rem.) The relation of the rem to other dose units depends on the biological effect under consideration and on the conditions of irradiation. Any of the following is considered to be equivalent to a dose of one rem: (1) A dose of 1 r due to X- or gamma radiation. (2) A dose of 1 rad due to X-, gamma or beta radiation. (3) A dose of 0.1 rad due to neutrons or high energy protons.
Roentgen	The roentgen was originally defined as that quantity of X or gamma radiation that would produce 1 electrostatic unit (esu) of electrical charge of either sign in 0.001293 grams of dry air (a volume of 1.00 cubic centimeter at standard temperature and pressure). This can be shown to be approximately equivalent to 1.61×10^{12} ion pairs per gram of dry air, or the release of about 84 ergs of energy per gram of dry air at standard temperature and pressure. The roentgen is now exactly defined as 2.58×10^{-4} C per kilogram. The number of roentgens produced by a radioactive source is easily measured using air ionization chambers. However, because the roentgen is a unit of radiation exposure, not dose, it does not provide exact information about the amount of radiation that is actually absorbed by a medium, or about the effects of the radiation on the medium.
Solubility	The ability of a substance to form a solution with another substance.

Specific Activity	The activity of the radionuclide per unit mass of that nuclide. See Radioactive.
Spontaneous Fission	Nuclear fission in which no particles or photons enter the nucleus from the outside.

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